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DISTRIBUTION OF METALS AND HYDROCARBONS IN THE NEARSHORE ZONE OF THE SOUTHERN BEAUFORT SEA

DISTRIBUTION OF METALS AND HYDROCARBONS

IN THE

NEARSHORE ZONE OF THE SOUTHERN BEAUFORT SEA

Conservation and Protection
Environmental Protection
Northwest Territories District Office
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ABSTRACT

A survey of metals and hydrocarbons in bottom sediments was carried out in the Nearshore Zone of the southern Beaufort Sea in the summer of 1984. Forty three stations were sampled in the area between Herschel Island (Yukon) and Russell Inlet (N.W.T.). All samples were analyzed for Cr, Fe, Ni, Cu, Ba, Zn, Cd, Hg, Pb, particle size, alkanes, and polycyclic aromatic hydrocarbons. Data were statistically analyzed in order to assess the differences in metal and hydrocarbon concentrations between the areas located to the east and west of the Mackenzie River Delta. The results indicated that four metals (Ba, Ni, Zn, and Cd) were significantly higher at stations located to the east of the Mackenzie River Delta. Iron was significantly higher in the 15-20 cm core section in samples collected in the Herschel Basin (west of the Mackenzie River Delta) than in any other area. Terrigenous detrital material originating in vascular plant waxes is presumed to be the source of the alkanes found by this survey. The possible sources of the polycyclic aromatic hydrocarbons in this area are petroleum, combustion of fossil fuels, forest fires, and aromatization of naturally occurring precursors.It is recommended that a site specific study be undertaken to quantify the natural variability in the distribution of metals in the Nearshore Zone of the Southern Beaufort Sea. It is also recommended that a study be undertaken to distinguish and quantify natural and anthropogenic sources of polycyclic aromatic hydrocarbons.

RÉSUMÉ

Pendant l'été 1984, on a mesuré la teneur en métaux et hydrocarbures des sédiments infralittoraux de la partie méridionale de la mer de Beaufort. Les 43 stations d'échantillonnage se situaient entre l'île Herschel (Yukon) et Russel Inlet (T.N. - O.). Chaque échantillon fut analysé pour sa granulométrie et dosé pour les alcanes, les hydrocarbures polycycliques aromatiques (HPA) et les eléments Cr, Fe, Ni, Cu, Ba, Zn, Cd, Hg et Pb. Les differences entre échantillons à l'est et à l'ouest du delta du fleuve Mackenzie furent analysées statistiquement. Les résultats indiquent une teneur en quatre éléments (Ba, Ni, Zn et Cd) significativement plus élevée aux endroits à l'est du Delta. Il y avait significativement plus de fer dans le segment entre 15 et 20 cm des carottes prélevées dans le bassin Herschel (à l'ouest du Delta) que partout ailleurs. On présume que les alcanes proviennent de détritus terrigènes issus des cires de plantes vasculaires. Les hydrocarbures polycycliques aromatiques pourraient provenir du pétrole, de la combustion de carburants fossiles, des incendies de forêt et de l'aromatisation de précurseurs chimiques naturels. Nous recommandons une étude plus poussée de chaque site pour quantifier la variabilité naturelle de la distribution des éléments métalliques dans les sédiments infralittoraux du sud de la mer de Beaufort. Nous recommandons aussi d'entreprendre une étude pour partager et quantifier les sources naturelles et anthropogènes d'hydrocarbures polycycliques aromatiques.

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1.0 INTRODUCTION

During the past decade the southern Beaufort Sea area has been the site of extensive oil and gas exploration. Environmental concerns have been raised by various governmental agencies, northern communities and public interest groups regarding the impact of oil and gas exploration and possible production on the sensitive arctic marine environment. In July, 1984, the Environmental Protection Service (EPS), of the Department of Environment (DOE), Northwest Territories District, carried out a bottom sediment survey program in the Nearshore Zone of the southern Beaufort Sea in order to collect baseline information on the distribution of metals and hydrocarbons (Figure 1).

The objectives of the survey were:

(i) to determine baseline concentrations of metals and hydrocarbons along the 10 m isobath of the southern Beaufort Sea in areas where offshore oil and gas exploration has already occurred and exploration and potential production are most likely to occur; and,

(ii) to examine the influence of the Mackenzie River discharge and its associated plume on the distribution of metals and hydrocarbons in the bottom sediments of the southern Beaufort Sea.

A data report presenting the metal and hydrocarbon concentrations and describing the analytical methods used for processing the sediment samples has been produced (Can Test Ltd., 1985). The purpose of the present report is to summarize

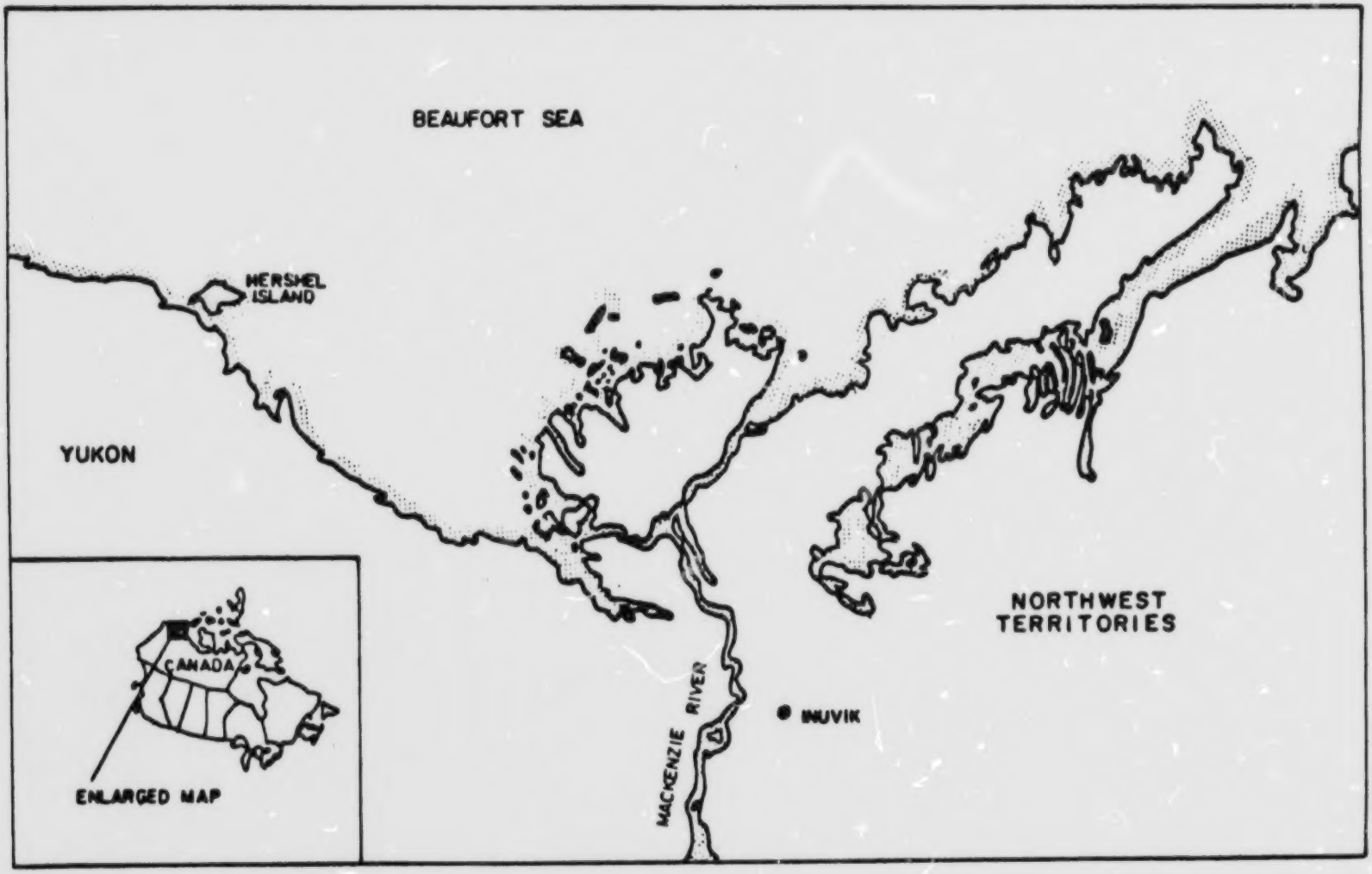


FIGURE 1. LOCATION OF THE STUDY AREA

and interpret the data, and to recommend future monitoring.

2.0 STUDY AREA

The study area extended from Herschel Island off Yukon Coast to Russell Inlet on the Tuktoyaktuk Peninsula (Figure 2). Along the Tuktoyaktuk Peninsula, the stations were located on the 10 m isobath, approximately 12-15 km apart. In Herschel Basin, a more intensive sampling program was carried out (Figure 3) to provide more detailed data on the distribution of metals and hydrocarbons in this area.

3.0 MATERIALS AND METHODS

3.1 Field Methods - Positioning and Sampling.

Sediment core samples were collected from the "M.V. Sequel" (15 meter research vessel), using either a mini-gravity corer or a triple Benthos gravity corer.

The location of each station was determined by a satellite navigation system aboard the "M.V. Sequel", and the error of positioning was estimated at $\pm$100 m. Sample station co-ordinates, dates of sampling, core lengths, and water depths are presented in Appendix A.

In most cases, two sediment cores, 8 cm in diameter and ranging from 10 to 40 cm in length, were collected at each sampling site. Each core was sub-sampled within 24 hours of

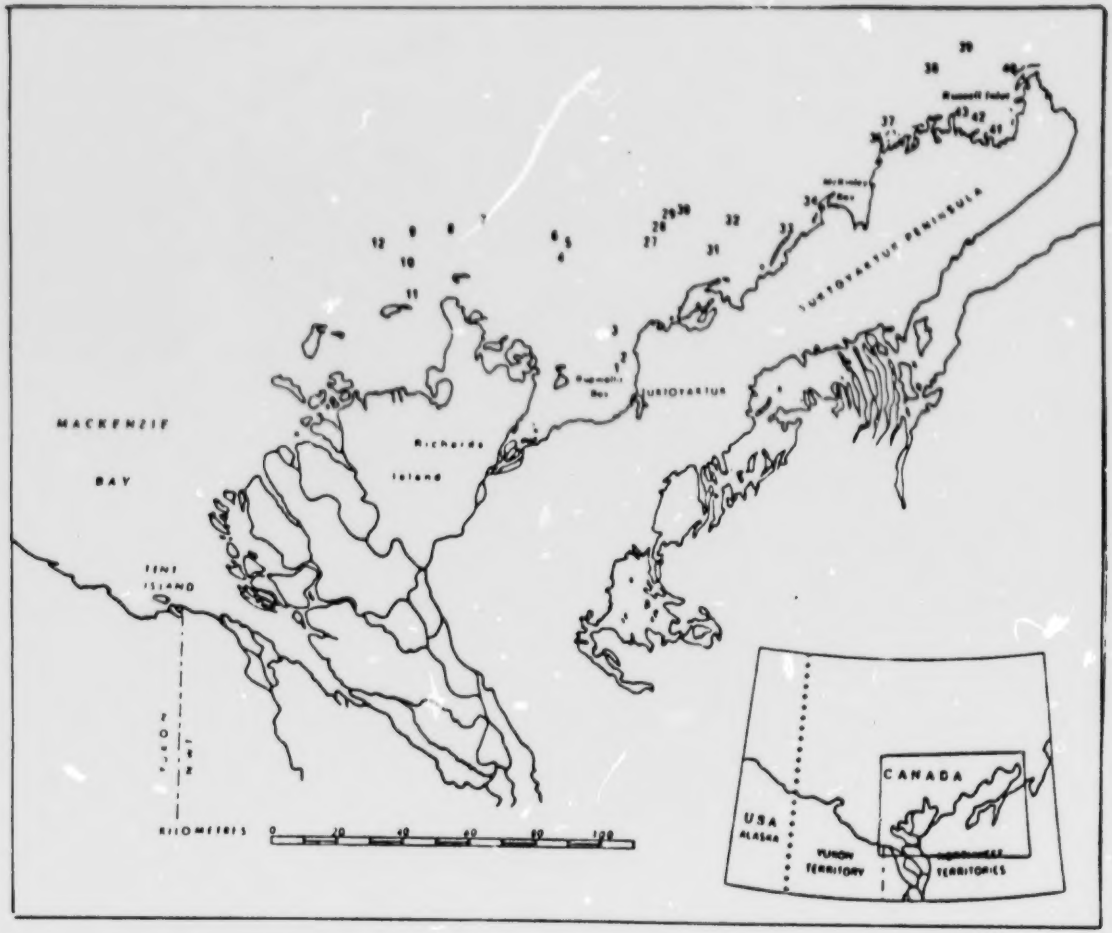


FIGURE 2. LOCATION OF SAMPLING STATIONS EAST OF THE MACKENZIE RIVER DELTA

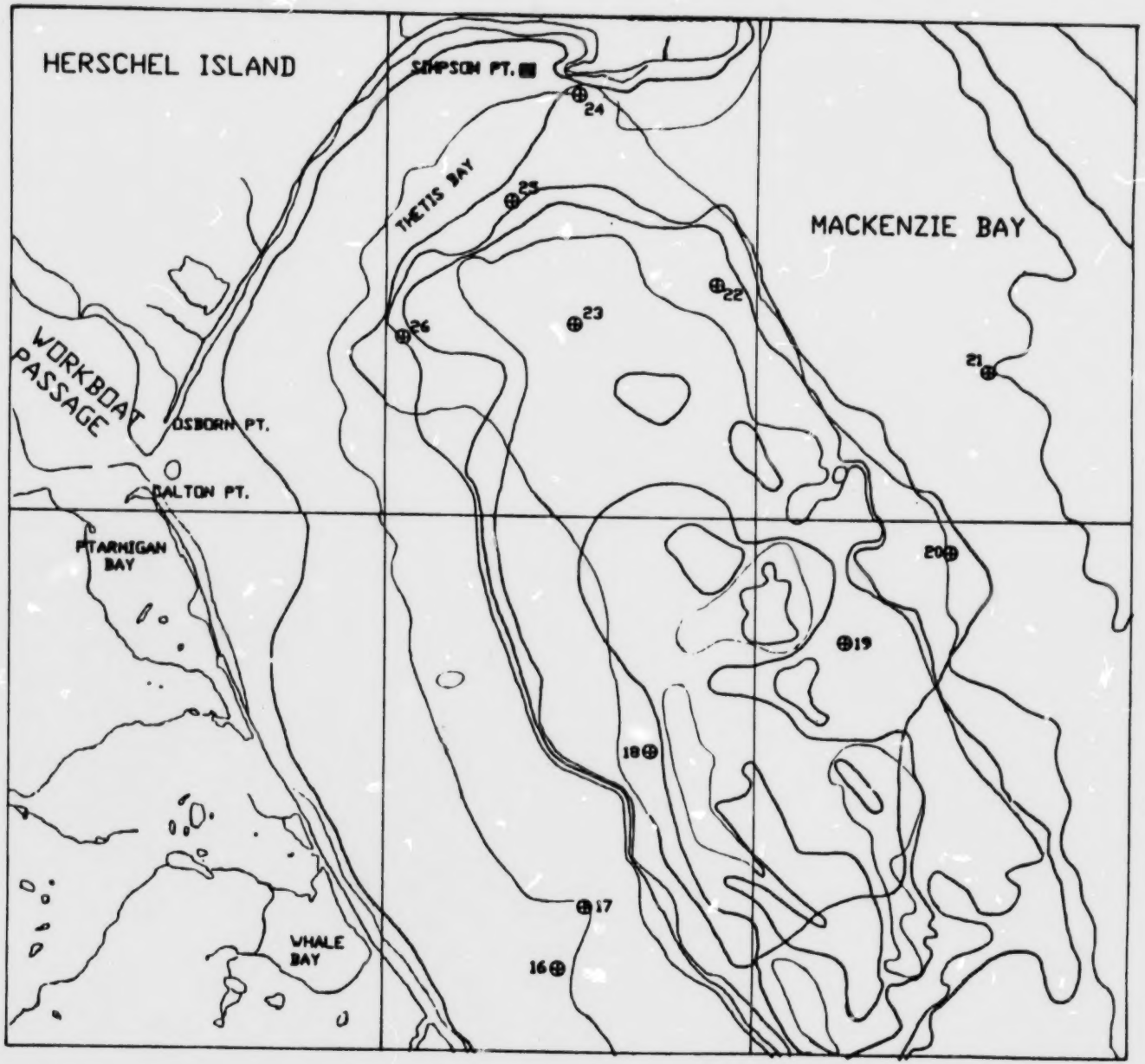


FIGURE 3. LOCATION OF SAMPLING STATIONS WEST OF THE MACKENZIE RIVER DELTA

collection into 5 cm sections using a core extruder and a teflon spatula. Each 5 cm sub-sample was placed in a Whirlpak bag and frozen immediately in an on-board freezer.

At some stations, a firm sandy bottom did not allow for the collection of core samples. At these stations, a Van Veen sampler was used to obtain a grab sample. A sub-sample was taken from the center of the collected sample with a teflon spatula in order to prevent contamination of the sub-sample from the metallic parts of the sampler. Each sub-sample was placed in a Whirlpak bag and frozen immediately in an on-board freezer.

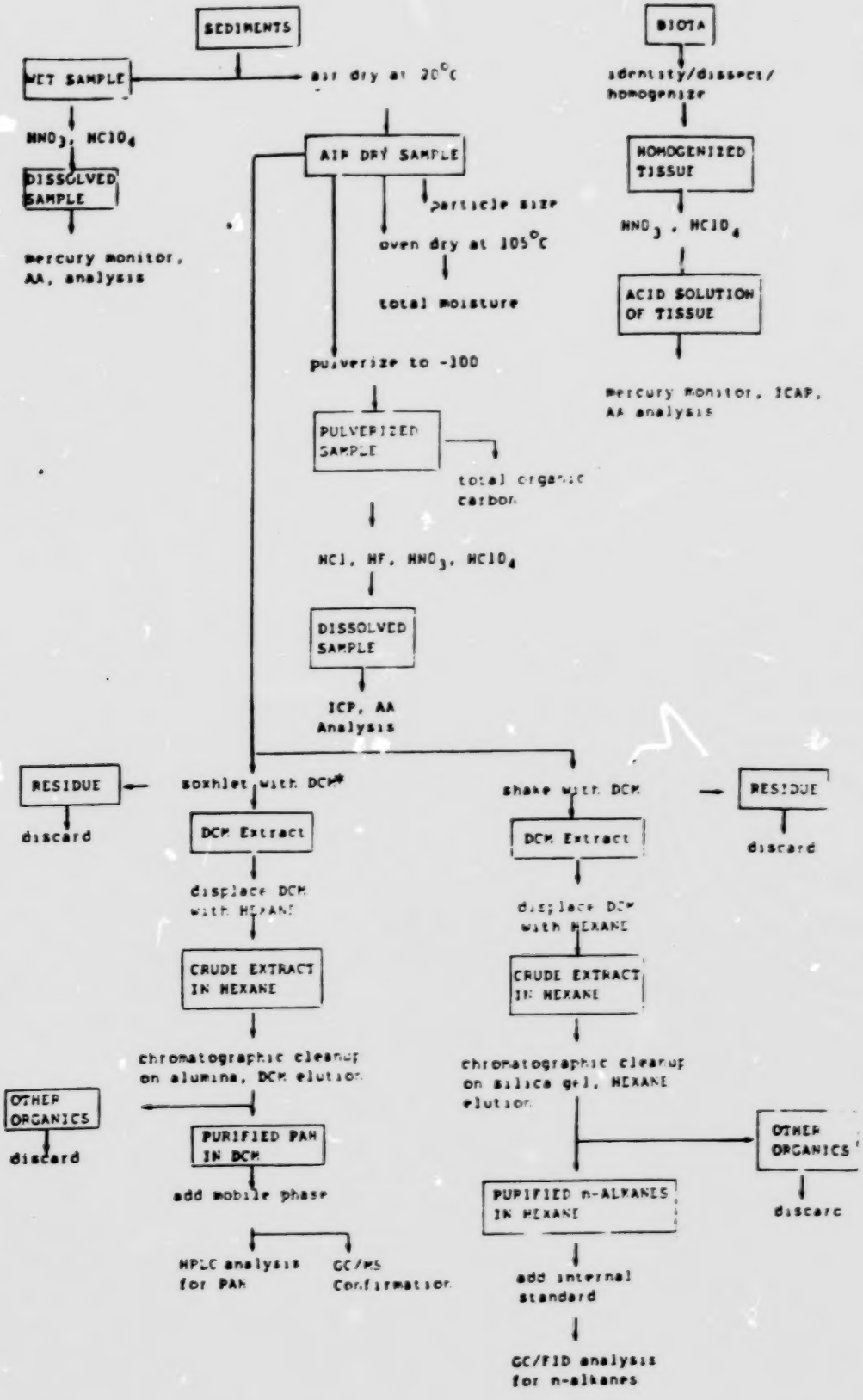
3.2 Laboratory Methods

A flowchart summarizing the analytical processing of each sample is shown in Figure 4, and details of analytical methods reported by Can Test (1985) are described in Appendix B. Metal detection limits are presented in Table 1 and PAH detection limits are presented in Table 8.

3.3 Statistical Methods.

To investigate the geochemical characteristics of the sediments, and to understand the significance of the concentrations of metals and hydrocarbons, descriptive statistics, Pearson correlation coefficient and one-way Analysis of Variance (ANOVA) followed by Least Significant Difference (LSD) multiple comparison test were carried out at the 0.05 level of significance.

Due to logistic problems at the time of sampling, an



* - dichloromethane

FIGURE 4. FLOWCHART SUMMARIZING THE ANALYTICAL PROCESSING OF EACH SAMPLE

TABLE 1. METAL DETECTION LIMITS

ELEMENT ANALYSIS	Ba ICP	Cr ICP	Cu ICP	Fe ICP	Ni ICP	Zn ICP	Hg Hg-M	Cd AA-GF	Pb AA-F
Technique Detection Limit ($mg.L^{-1}$ in solution)	0.001	0.030	0.025	0.03	0.025	0.015	0.001	0.001	0.10
Sample Weight (g)	0.50	0.50	0.50	0.50	0.50	0.50	3	3	3
Final Volume (ml)	50	50	50	50	50	50	50	50	50
Detection Limit ($ug.g^{-1}$)	0.1	3.	2.5	0.03%	2.5	1.5	0.02	0.20	2.

ICP - Plasma Analysis
Hg-M - Mercury Monitor
AA-GF - Atomic Absorption Graphite Furnace
AA-F - Atomic Absorption, Flame

Note: In this study, detection limit is based on two components: the instrumental "detection limit", and the sample weight and the final volume of the sample digestate.

Instrumental detection limit is usually defined as "equal to two times the standard deviation of the background noise".

For ICP analysis, the standard deviation of the background noise is easily determined using the instrument's on-board computer as a blank sample is analysed repeatedly. For ICP, the usual "Limit of Quantification" is ten times the standard deviation. These Limits of Quantification are presented as the detection limit in the above table.

unequal number of replicate samples was collected at various stations. The values for replicates obtained at each station were averaged, and the mean values were used in the data

analysis. This resulted in a diminished measure of variability but increased the probability of the values being independent, and also increased the validity of the statistical tests used.

It has been shown that the highest metal and hydrocarbon concentrations are normally associated with fine-grained sediments (Forstner and Wittman, 1981; Neff, 1979). Such sediments consist of at least 80 % silt and clay particles. Consequently, accurate comparison of metal and hydrocarbon concentrations required that the compounding effect of sediment particle size be recognized. The data were therefore divided into groups of high and low silt-clay content.

A further division of the data set was carried out in order to account for the potential influence of the Mackenzie River discharge. This division was based on location in relation to the Mackenzie River delta.

As a result, eight groups of data were available for statistical analysis and data interpretation:

Group No.	Location (in relation to Mackenzie River Delta)	%Silt-Clay	Core Sub-sample (cm)
1	East of Delta	81 - 100	0 - 5
2	East of Delta	81 - 100	15 - 20
3	West of Delta	81 - 100	0 - 5
4	West of Delta	81 - 100	15 - 20
5	East of Delta	0 - 80	0 - 5
6	East of Delta	0 - 80	15 - 20
7	West of Delta	0 - 80	0 - 5
8	West of Delta	0 - 80	15 - 20

Prior to carrying out any statistical tests, the data were tested for normality and homoscedasticity. Sediment containing

80% silt-clay contained the highest concentrations of metals and hydrocarbons; therefore, data in groups 1-4 were used for further analysis.

3.3.1 Testing of Normality. The Z-test for skewness, as described by Tabachnik and Fidell (1983), was used to test the data set from groups 1 - 4 for normality. The results of this test are shown in Appendix C. In only 3 out of 48 tests (6%) was the hypothesis of normality rejected.

3.3.2 Testing of Homoscedasticity. Homoscedasticity, or the homogeneity of variances, is an important precondition for several statistical tests. The F_{max}-test (Sokal and Rohlf, 1969) was used to test for homoscedasticity. The data from groups 1 - 4 were used (12 variables each). The results of these tests are shown in Appendix D. In 10 out of 12 tests (83%) the hypothesis of homoscedasticity could not be rejected.

The second test for homoscedasticity was the ratio of the largest n : smallest n (Tabachnick and Fidell, 1983). The ratio should not be greater than 4.0. The ratio obtained using the data of the present study was 3.75, again indicating that the hypothesis of homoscedasticity could not be rejected.

The third test for homoscedasticity was the regression of the standard deviation against the mean. This technique is recommended by Sokal and Rohlf (1981) to identify variance/mean patterns. The results of the test are shown in Appendix E, and indicated that the slope of the regression line was not significantly different from zero.

4.0 RESULTS AND DISCUSSION

4.1 Sediment Particle Size.

Particle size distribution of sediments in groups 1-8 is shown in Figures 5-8 and is presented in Appendix G. The distribution of fine and coarse grained sediment in the area east of the Mackenzie River Delta corresponded well to the primary and secondary sinks, respectively, as outlined in the sediment dispersal model of Harper and Penland (1982). The model is shown in Figure 9. The distribution of the fine particle size (81-100 % silt-clay) was similar in the top 5 cm and in the 15-20 cm section, with the exception of stations 32 and 33 (Figures 5 and 6). This distribution pattern indicates that the source of the sediments has not changed from the time of deposition of sediment at the 20 cm depth to the present.

In the area located to the west of the Mackenzie River Delta, the distribution pattern of the sediment appeared to be controlled by bottom morphology and by Herschel Island. Sediments with high silt-clay contents were found at stations located in the deep water areas of the Herschel Basin, which are also protected by Herschel Island (Figure 7). Sediments with a low silt-clay content were found in the shallower waters surrounding the depositional basin (Figure 8).

4.2 Metals.

A summary of the metal data from each area is presented in Table 2, and the detailed metal data set is presented in

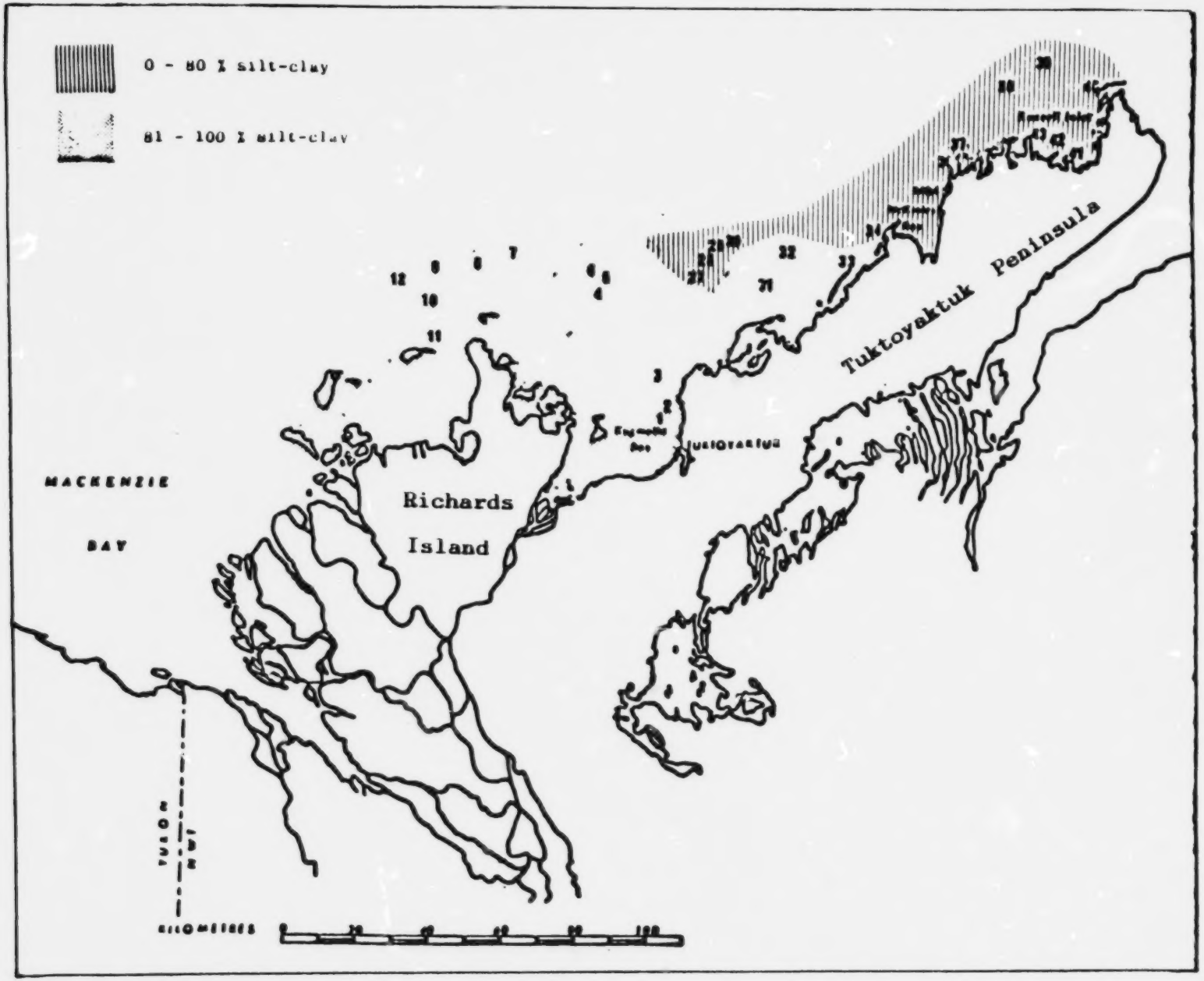


FIGURE 5. PATICLE SIZE DISTRIBUTION IN THE TOP 5 CM EAST OF THE MACKENZIE RIVER DELTA

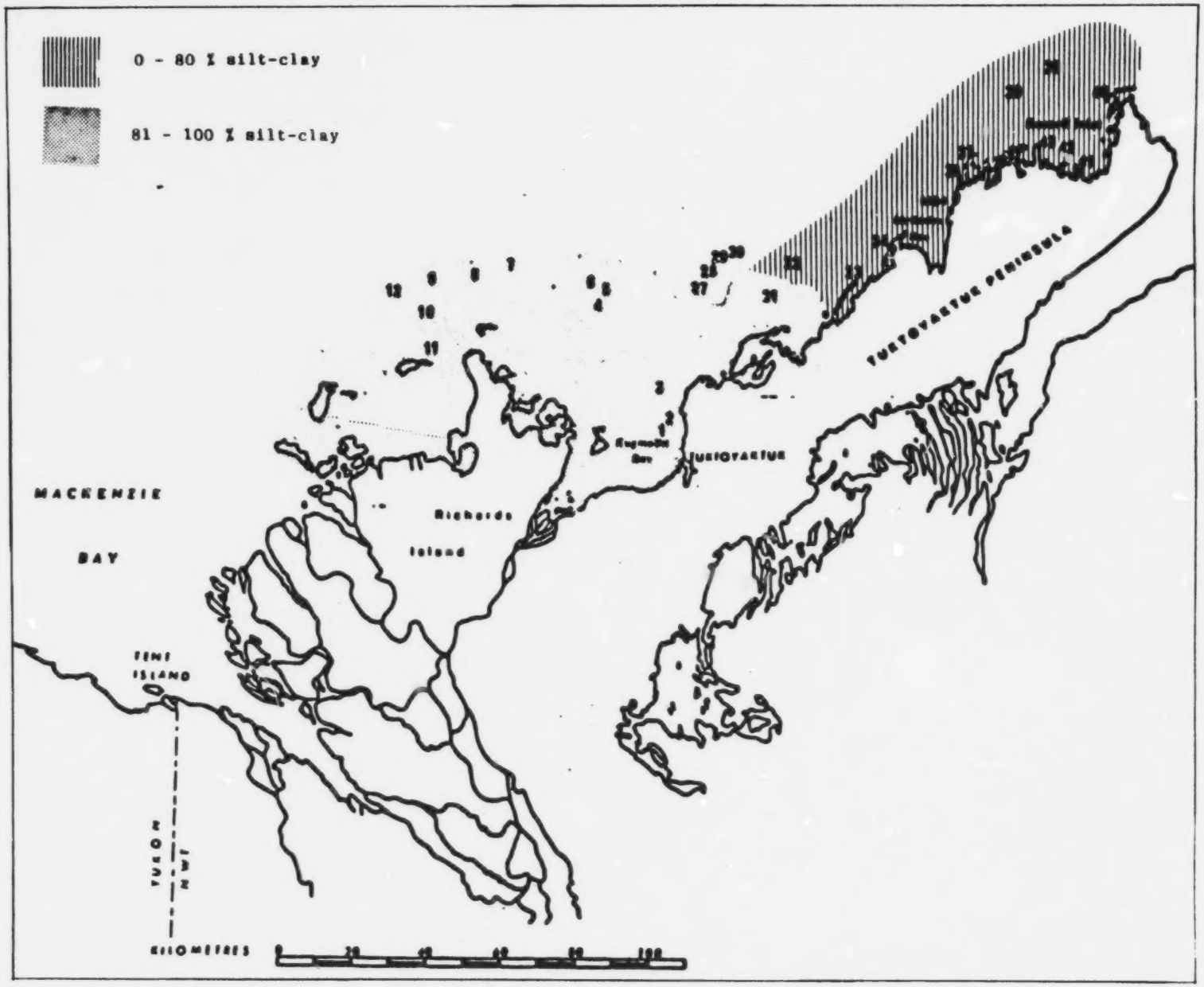


FIGURE 6. PARTICLE SIZE DISTRIBUTION IN THE 15 - 20 CM CORE SECTION EAST OF THE MACKENZIE RIVER DELTA

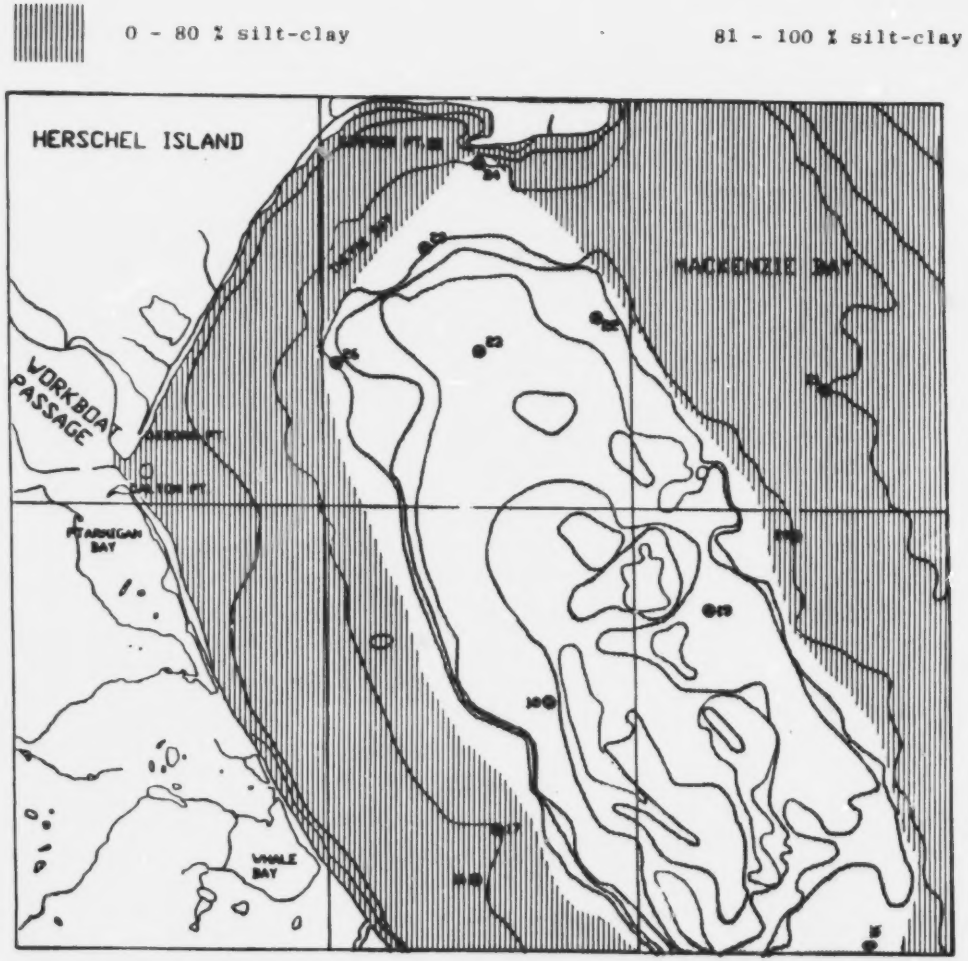


FIGURE 7. PARTICLE SIZE DISTRIBUTION IN THE TOP 5 CM WEST OF THE MACKENZIE RIVER DELTA

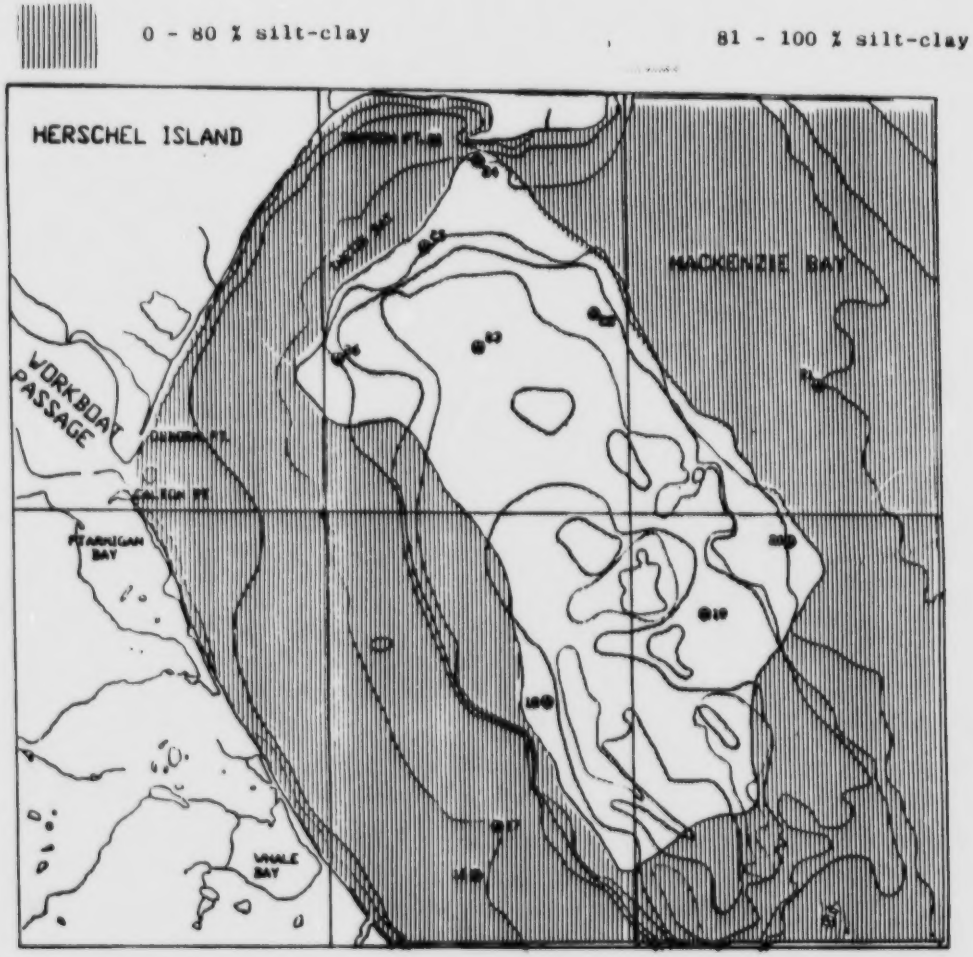


FIGURE 8. PARTICLE SIZE DISTRIBUTION IN THE 15 - 20 CM CORE SECTION WEST OF THE MACKENZIE RIVER DELTA

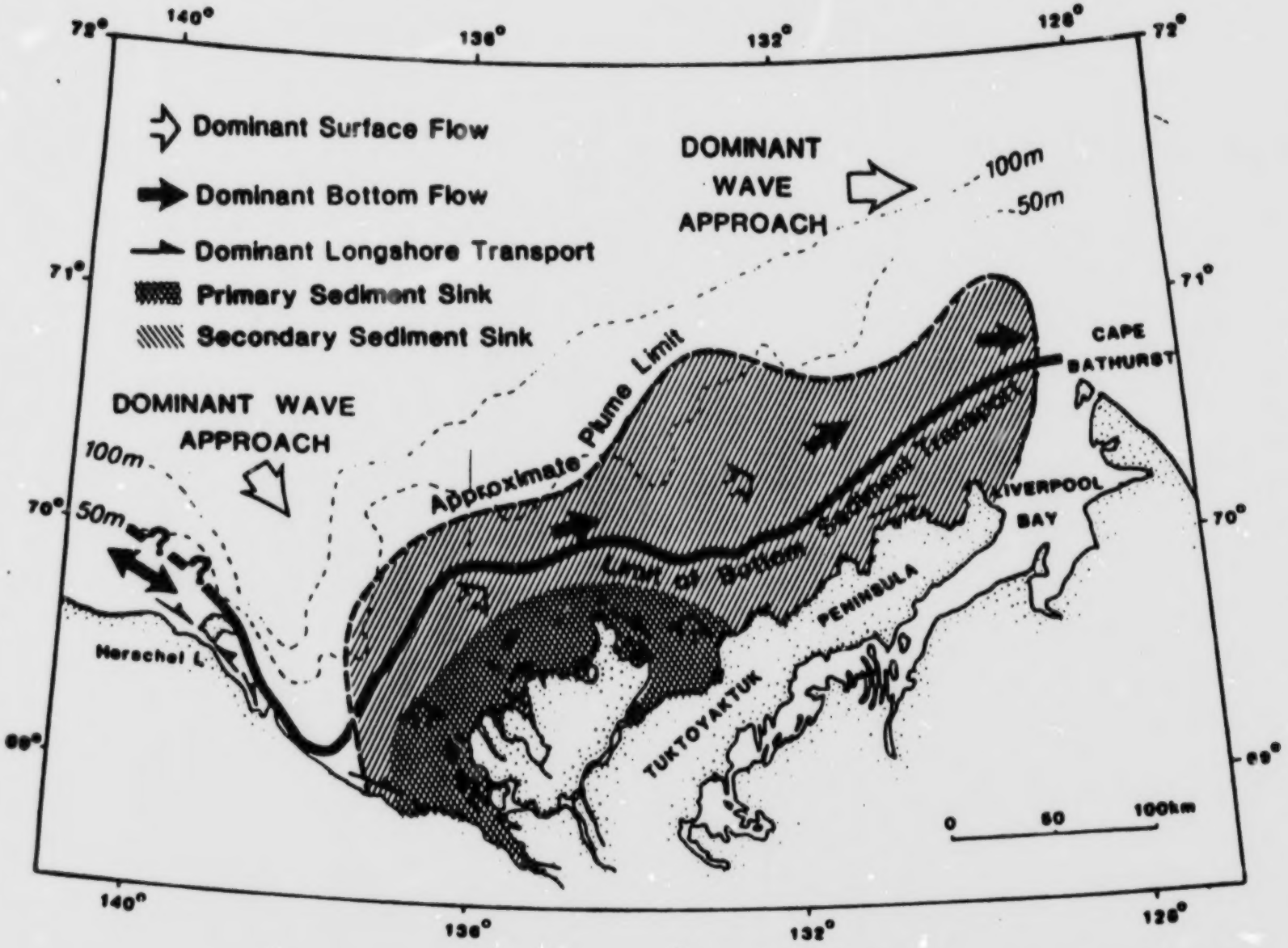


FIGURE 9. SEDIMENT DISPERSAL MODEL FOR THE SOUTHERN BEAUFORT SEA (after Harper and Penland, 1982)

TABLE 2. DESCRIPTIVE STATISTICS FOR THE METAL DATA

Location	Sand	Silt	Clay	Ba	Cr	Cu	Fe	Ni	In	Hg	Cd	Pb
	%	%	%	$\mu g \cdot g^{-1}$	$\mu g \cdot g^{-1}$	$\mu g \cdot g^{-1}$	%	$\mu g \cdot g^{-1}$	$\mu g \cdot g^{-1}$	$\mu g \cdot g^{-1}$	$\mu g \cdot g^{-1}$	$\mu g \cdot g^{-1}$
Group 1												
Min.	0.1	39.60	38.60	803	66	24	3.2	35	114	47	200	13.6
Max.	4.7	57.00	60.30	920	90	37	3.8	46	157	90	750	19.9
Mean	1.0	47.13	51.91	846	79	30	3.5	41	135	66	330	17.0
St.Dev.	1.44	4.84	5.57	33.1	5.5	3.1	0.18	2.8	10.6	10	140	1.63
Group 2												
Min.	0.20	32.00	36.00	842	70	25	3.34	41	124	58	210	13.7
Max.	2.90	61.30	67.90	902	84	31	3.84	48	136	65	280	17.1
Mean	0.95	46.35	52.80	859	80	29	3.56	43	131	63	250	15.6
St.Dev.	1.30	12.09	13.18	28.7	7.4	2.5	0.21	3.5	5.7	4	30	1.78
Group 3												
Min.	0.60	27.30	37.70	636	73	26	3.21	32	95	54	170	14.8
Max.	19.00	59.70	72.00	946	104	35	4.20	48	151	110	310	20.0
Mean	4.17	39.44	56.12	738	86	31	3.75	40	123	73	211	17.4
St.Dev.	6.10	10.97	12.99	90	11.6	3.48	0.31	5	17.9	15	56	1.8
Group 4												
Min.	0.70	36.00	39.50	618	78	26	3.02	35	106	60	140	14.7
Max.	15.00	59.50	61.70	751	90	31	3.73	42	129	70	124	18.0
Mean	4.38	43.22	52.43	714	83	29	3.40	38	117	63	199	16.2
St.Dev.	5.19	8.69	8.64	44	4.6	1.8	0.25	2.3	7.1	5	43	1.1
Group 5												
Min.	21.10	0.10	0.10	341	7.7	3.4	0.66	7	18	2	30	1.43
Max.	99.80	43.20	35.80	805	60	20	2.84	49	104	40	230	11.8
Mean	80.45	8.58	10.97	596	34	10	1.80	23	53	16	106	5.8
St.Dev.	25.64	12.97	12.16	152	18	6.1	0.79	13	29	14	71	3.58
Group 6												
Min.	N.D.	N.D.	N.D.	710	39	16	2.18	23	78	30	140	11.3
Max.	N.D.	N.D.	N.D.	854	87	28	3.55	42	137	60	320	17.8
Mean	N.D.	N.D.	N.D.	782	63	22	2.87	32	107	45	238	14.6
St.Dev.	N.D.	N.D.	N.D.	102	34	8.5	0.97	13	41.7	20	127	4.59
Group 7												
Min.	37.60	5.00	10.90	457	33	12	2.31	24	62	30	90	7.5
Max.	84.10	35.70	26.80	631	58	23	3.00	38	84	40	140	10.3
Mean	59.60	21.86	18.60	536	50	18	2.62	34	75	35	124	9.0
St.Dev.	16.81	11.02	6.00	71	10	4	0.29	5.8	9.6	7	21	1.2
Group 8						n = 1						
Min.												
Max.						Not sufficient data						
Mean												
St.Dev.						-						

Appendix G. In this study, the analytical methodology used for determining the particle size was sensitive enough to distinguish between silt and clay particles. This has not been the case in previous studies carried out in the Beaufort Sea area (Heath and Thomas, 1983; Erickson et al., 1983).

The results of the Pearson correlation test are summarized in Table 3. Correlation between silt, clay, and all metals was significantly positive when data from all areas were pooled together. When the data were partitioned to represent specific areas, clay showed significant positive correlation or no correlation with metals, and silt showed significant negative correlation or no correlation with metals. This indicated that metals in each area were associated with particles smaller than 4 um (clay).

The results of the quality control program (Appendix B) provided evidence that the cadmium data are reliable. Cadmium showed a significant positive correlation with all parameters when the data from all stations were pooled, but showed no significant correlation with the rest of the measured parameters when the data were partitioned into specific groups. Consequently, it is assumed that either the source of cadmium is different from that of all other metals, or that the physico-chemical factors controlling the distribution of cadmium in the sediment are different from those affecting all other metals.

In order to investigate the significance of the descriptive statistics shown in Table 2, one-way ANOVA followed by Least Significant Difference (LSD) multiple comparison tests were

TABLE 3. PEARSON CORRELATION COEFFICIENTS FOR SAND, SILT, CLAY, AND HEAVY METAL CONCENTRATIONS FOR THE GROUPS 1-4, POOLED AND SEPARATELY

	sand					silt					clay					Ba					Cr					Cu					Fe					Ni					Zn					Hg					Cd					Pb				
	A	1	2	3	4	A	1	2	3	4	A	1	2	3	4	A	1	2	3	4	A	1	2	3	4	A	1	2	3	4	A	1	2	3	4	A	1	2	3	4	A	1	2	3	4	A	1	2	3	4	A	1	2	3	4
sand	--------	-				-					--					-					--					-					-					-					--					-					-					--				
silt	-	--------				+	+	+	+	+	--	--	--	--	--	+	+	+	+	+	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	--	--	--	--	--	+	+	+	+	+	-	-	-	-	-	+	+	+	+	+	+	+
clay	--	+	+	+	+	--	--	--	--	--	--------					+	+	+	+	+	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	--	--	--	--	--	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Ba	-	+	+	+	+	-	-	-	-	-	+	+	+	+	+	--------					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Cr	--	+	+	+	+	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	--------					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Cu	-	+	+	+	+	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	--------					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Fe	-	+	+	+	+	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	--------					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Ni	-	+	+	+	+	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	--------					+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Zn	--	+	+	+	+	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	--------					+	+	+	+	+	+	+	+	+	+	+	+	+
Hg	-	+	+	+	+	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	--------					+	+	+	+	+	+
Cd	-	+	+	+	+	-	-	-	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	--------					+	+	+	+	+
Pb	--	+	+	+	+	--	--	--	--	--	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	--------				

Note: A - data pooled together from groups 1 - 4
+ - signifies a significant positive correlation
- - signifies a significant negative correlation

carried out on data collected from groups 1-4. The results are presented in Table 4. Mercury, Cu, Cr, and Pb showed no significant differences between the groups. However, concentrations of Ba, Fe, Ni, Zn, and Cd were significantly different between certain groups.

The concentrations of Ba, Ni, Zn, and Cd were highest in 0-5 cm and 15-20 cm sediment sections collected east of the Delta. In this area, the sedimentation rate was estimated to be 3.0 $mm.yr^{-1}$ based on Pb^{210} dating (Hill, 1985). The 15-20 cm core section therefore represents the time interval from 1918 to 1934.

TABLE 4. ONE WAY ANOVA AND LEAST SIGNIFICANT DIFFERENCE MULTIPLE COMPARISON TESTS FOR DATA FROM GROUPS 1 - 4

Variable	Groups Compared 1/2	1/3	1/4	2/3	2/4	3/4	Rank of Mean Lowest			Highest
Barium		*		*	*		4	3	1	2
Chromium										
Copper										
Iron		*				*	4	1	2	3
Nickel			*		*		4	3	1	2
Zinc		*	*				4	3	2	1
Mercury										
Lead										
Cadmium		*	*				4	3	2	1

Note: * - indicates a significant difference between the two groups
1 - East of Delta, 0 - 5 cm, 81 - 100 % silt/clay
2 - East of Delta, 15 - 20 cm, 81 - 100 % silt/clay
3 - West of Delta, 0 - 5 cm, 81 - 100 % silt/clay
4 - West of Delta, 15 - 20 cm, 81 - 100 % silt/clay

Iron concentrations were highest in the 15 - 20 cm core sections collected west of the Mackenzie River Delta. Statistical analysis showed that input of iron has decreased significantly (at the 95 % confidence level) over time. Sedimentation rate in the Herschel Basin is estimated to be 0.28 $mm.yr^{-1}$, based on Pb^{210} dating (Hill, 1985). Consequently, the 15-20 cm core section represents the time interval from 1270 to 1449. Since no industrial development existed at that time, the decrease in iron concentrations in the top 5 cm in comparison with the 15-20 cm core section was probably caused by a natural change in the type of sediment deposited in this area.

The concentrations of metals found in this survey were compared to data from previous studies (Table 5). The data showed no trends of enrichment in metal concentrations in the area sampled.

4.3 Observations Derived from Statistical Analyses of Particle Size and Metal Data.

Based on the statistical analyses of the metal data, the following observations were made:

1) A significant negative correlation was found between sand and all the other measured parameters;
2) A significant positive correlation was found between silt and all metals when the data from all the stations were pooled together. There was a significant negative correlation when the data set was divided into groups representing specific areas;

TABLE 5. COMPARISON OF THE CONCENTRATIONS OF METALS FOUND IN THIS SURVEY AND OTHER PREVIOUS STUDIES.

Area (Reference)		Cr ug.g-1	Cu ug.g-1	Fe %	Ni ug.g-1	Zn ug.g-1	Hg ng.g-1	Cd ng.g-1	Pb ug.g-1
Tarsiut A-25 Thomas, 1978	Range	134-139	29-31	N.D.	97-104	138-139	77-85	210-230	N.D.
	Mean	137	31		100	139	82	220	
Tarsiut N-44 Thomas et al. 1982	Range	23-119	4-60	N.D.	5-69	18-146	6-151	72-290	N.D.
	Mean	78	21		42	100	61	210	
Tarsiut N-44 Heath and Thomas, 1983	Range	17-118	5-31	N.D.	18-71	31-149	16-106	70-530	N.D.
	Mean	78	23		50	106	74	280	
Issungnak Erickson et al., 1983	Range	47-139	11-30	N.D.	N.D.	51-168	35-180	150-400	N.D.
	Mean	113	24			121	88	250	
West Tarsiut Gulf, 1984	Range	61-72	27-29	N.D.	65-68	149-157	110-180	248-269	N.D.
	Mean	67	28		67	152	137	259	
this study 1984	Range	8-104	3-37	0.7-3.8	7-48	18-157	2-110	30-750	1.4-20
	Mean	66	24	3.0	36	102	52	200	13

Notes: No data were available for distribution of barium
All of the above listed data were collected in the immediate vicinity of artificial islands, with the exception of Gulf (1984).

3) Cadmium did not correlate with any other analysed metal when the data set was divided into specific groups;
4) Significant differences were observed in the concentrations of barium, iron, nickel, zinc, and cadmium from areas located to the east and west of the Mackenzie River Delta. However, no significant differences were found in the concentrations of these metals between the top 5 cm core sections and the 15-20 cm core sections;
5) Significant differences were found in the concentration of iron between the top 5 cm core section and 15-20 cm core section in sediment collected in Herschel Basin.

4.4 Hydrocarbons.

A summary of the concentrations of total PAH (defined as the sum of the resolved 16 individual compounds), total organic carbon, total alkanes ($n\text{-}C_{12}$ to $n\text{-}C_{36}$) and the alkane nonacosane ($n\text{-}C_{29}$) in individual sediment groups (see page 9 for group descriptions) is presented in Table 6. Detailed results of the hydrocarbon analysis (alkanes and TOC) are shown in Appendix F.

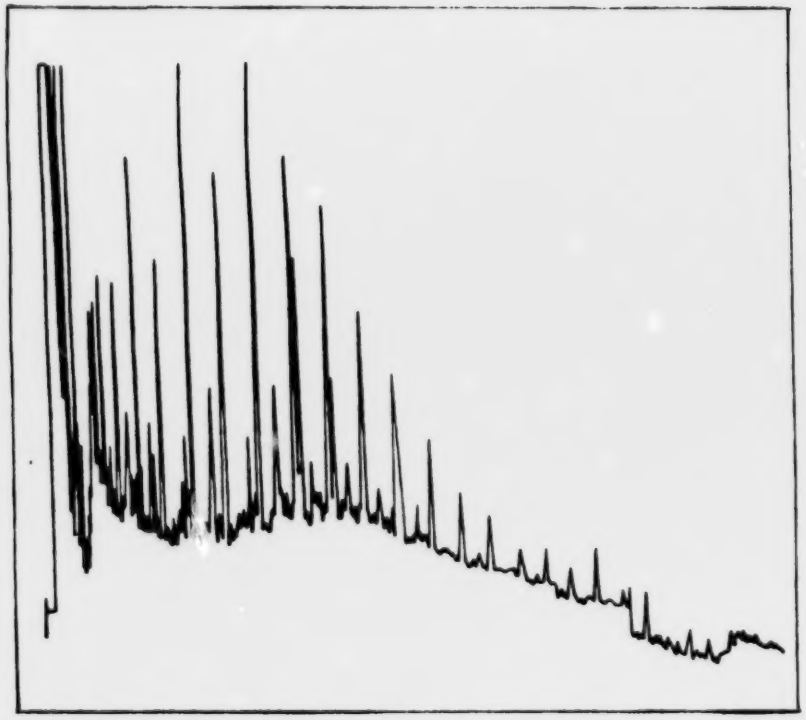
4.4.1 Alkanes. Representative chromatographs of the extracts are shown in Figure 10. The following observations were made with regard to the composition and distribution of alkanes in the collected sediments:

1. The representative chromatographs shown in Figure 10 show bimodal distributions of n-alkanes, with local maxima present at $n\text{-}C_{14}$ and $n\text{-}C_{31}$, which could indicate that mixed

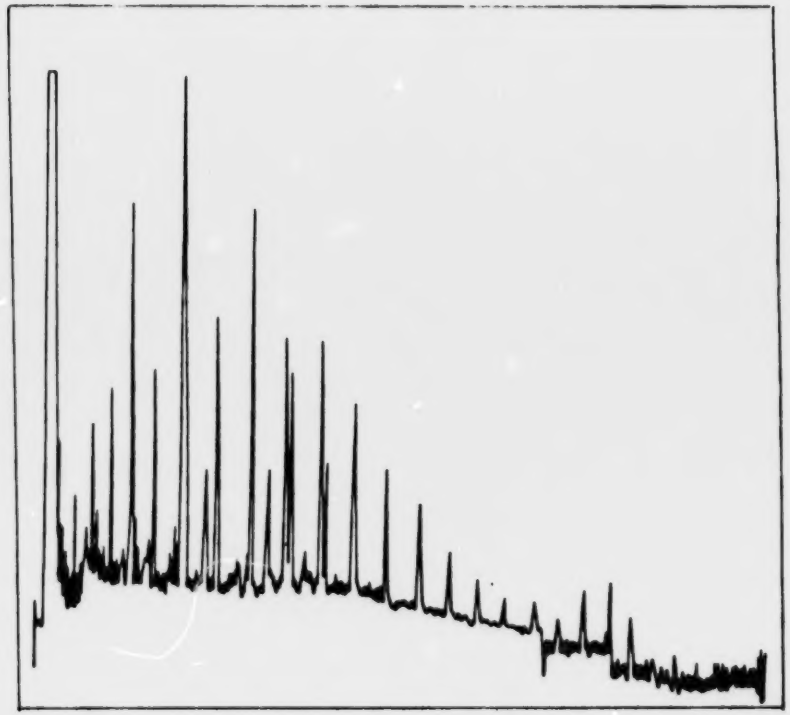
TABLE 6. SUMMARY OF THE HYDROCARBON DATA

Location	TOC %	Total PAH $ng.g^{-1}$	Total Alkanes $ng.g^{-1}$	C-29 $ng.g^{-1}$
Group 1				
Min.	0.87	665	1220	7
Max.	1.66	1240	2810	94
Mean	1.17	960	1790	25
St.Dev.	0.19	168	530	23
Group 2				
Min.	0.95	714	1180	12
Max.	1.37	946	1860	18
Mean	1.14	782	1550	15
St.Dev.	0.18	110	290	3
Group 3				
Min.	0.92	180	2348	58
Max.	1.35	1091	4213	249
Mean	1.08	439	3316	122
St.Dev.	0.12	436	596	61
Group 4				
Min.	0.91	197	2254	58
Max.	1.07	486	3421	126
Mean	1.02	295	2668	107
St.Dev.	0.06	165	420	25
Group 5				
Min.	0.08	20	195	5
Max.	0.87	399	3191	43
Mean	0.33	107	1204	16
St.Dev.	0.26	145	949	13
Group 7				
Min.	0.37	N.D.	1097	37
Max.	0.70	N.D.	2919	72
Mean	0.54	N.D.	2200	56
St.Dev.	0.14	N.D.	829	13

Note: N.D. - not sufficient data
- groups 6 and 8 contained n=2 and n=1 respectively, and consequently, no summary is provided

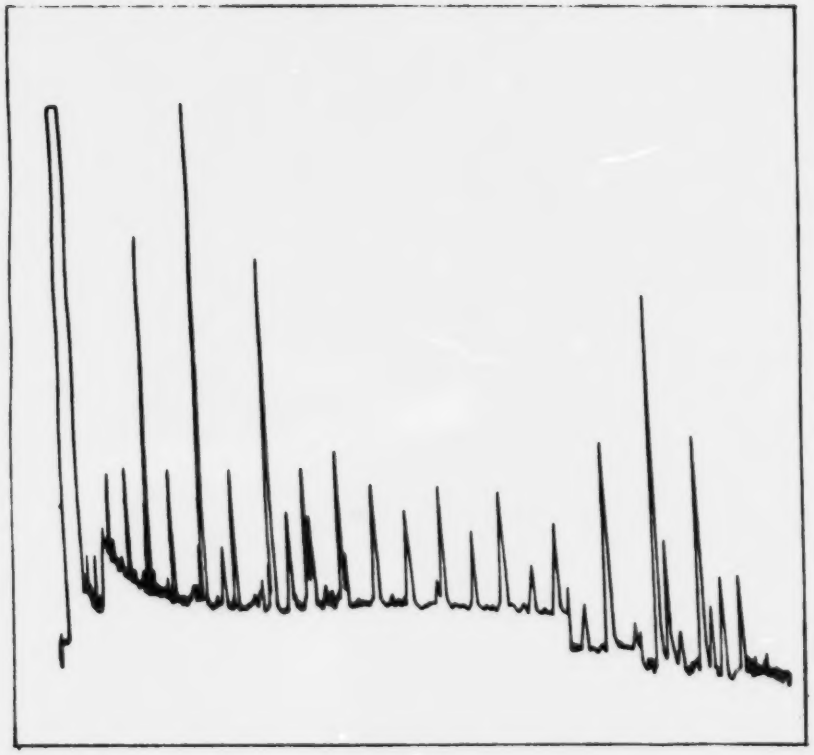


Station #5, 0 - 5 cm

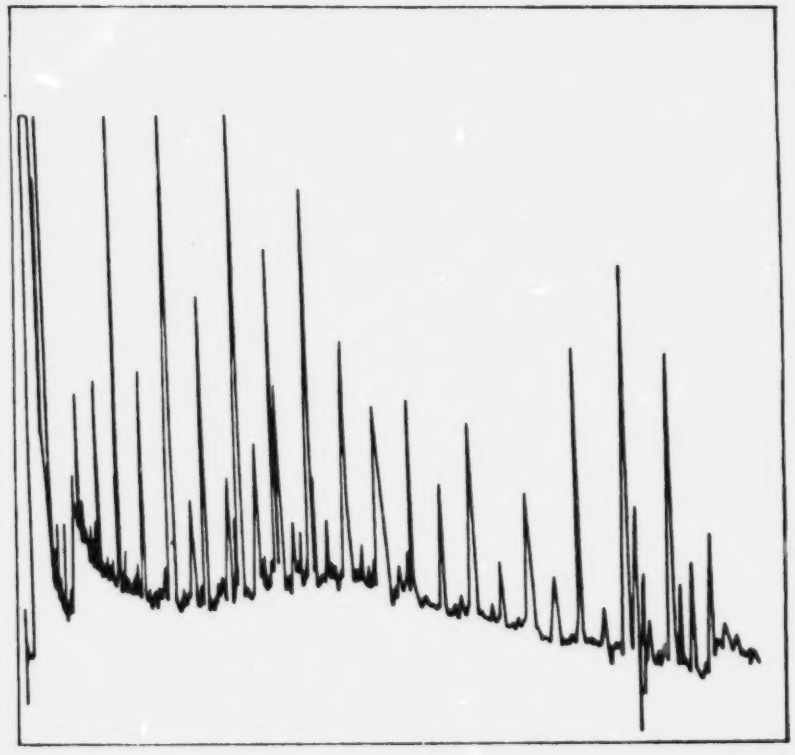


Station #7, 15 - 20 cm

FIGURE 10. REPRESENTATIVE CHROMATOGRAPHS OF THE ALKANE EXTRACTS

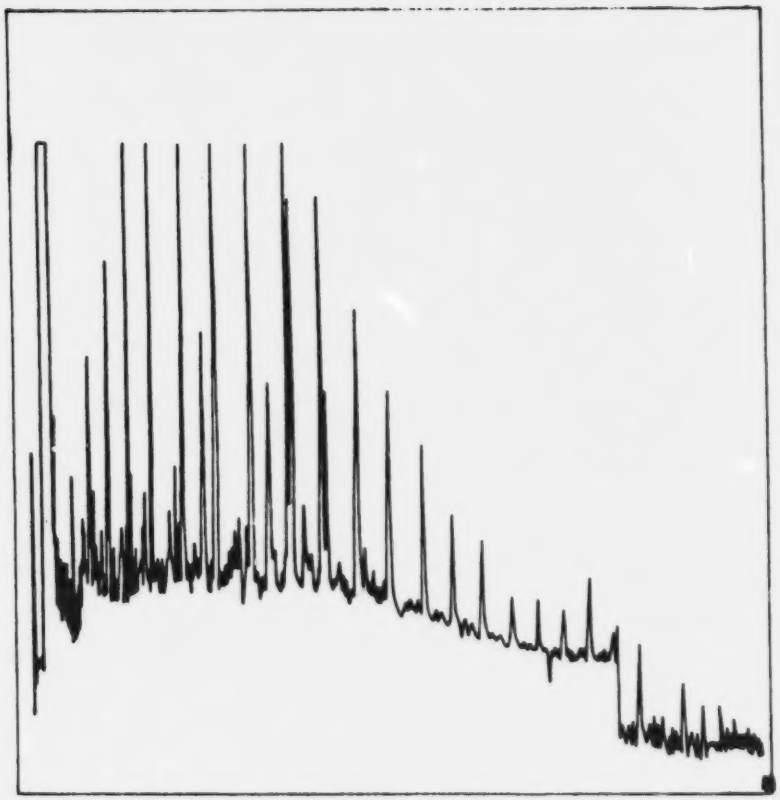


Station #26, 0 - 5 cm

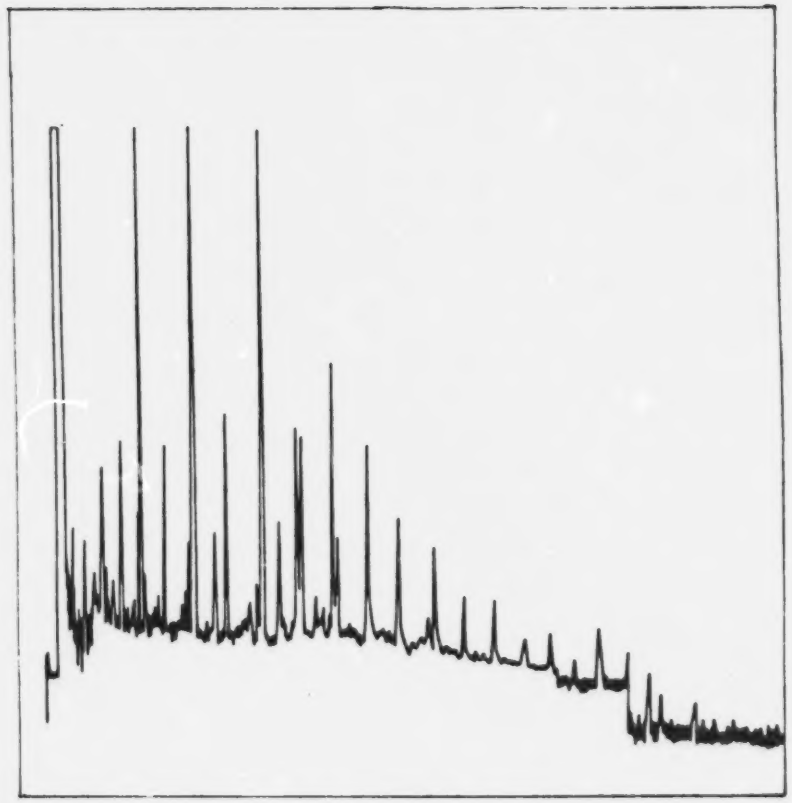


Station #26, 15 - 20 cm

FIGURE 10. Continued



Station #31, 15 - 20 cm



Station #40, 0 - 5 cm

FIGURE 10. Continued

marine and terrestrial hydrocarbons were present, although microbial modification may affect the distribution. (Brown et al., 1972; Johnson and Calder, 1973).

2. There was no indication of a petrogenic source of alkanes which would be characterized by high n-alkane distribution from n-C_{15} to n-C_{22} and an unresolved complex mixture (UCM). The UCM is a key hydrocarbon assemblage, mainly containing a mixture of co-eluting cyclo-paraffins and naphtheno-aromatic compounds, which can not be resolved into individual components on capillary columns (Boehm et al., 1978; Boehm et al., 1980; Piotrowicz et al., 1978).

3. Material derived from phytoplankton which is usually characterized by the presence of n-C_{15} and n-C_{17} (Smith et al., 1983; Boehm et al., 1980) was not present.

4. A source of terrigenous detrital material originating in vascular plant waxes, characterized by odd-carbon homologs between n-C_{23} and n-C_{31} (Smith et al., 1983; Hamilton et al., 1984; Barrick et al., 1980) was present.

5. Nonacosane (n-C_{29}), which is derived from terrigenous plant material, but can also be present in crude oil, was present. Where there is a strong odd-carbon-chain over even- carbon-chain preference and a lack of a distinct UCM, *a terrigenous biogenic* source of n-C_{29} is indicated (Boehm and Farrington, 1984). Such a preference was found in this study and supports the hypothesis stated under 4 (preceding).

6. The predominance of pristane (pristane/phytane ratio >> 1 which was found in sediments collected in this study) can be interpreted as an indication of biogenic inputs based on the occurrences of phytane as a biolipid. Such occurrences are rare, save for petroleum (Hamilton et al., 1984; Barrick et al., 1980; Tissot and Welte, 1978). A pristane/phytane ratio approaching unity in marine sediment has been cited as evidence of oil pollution (Tissot and Welte, 1978), but this ratio has to be used with caution, since Tissier and Oudin (1973) found a pristane/phytane ratio of almost unity in several unpolluted sediment samples in the estuarine environment on the French Coast of the English Channel. They attributed this phytane occurrence to bacteria in which both pristane and phytane are constituents. In the Beaufort Sea, Wong et al. (1976) suggested that the same mechanism could account for the presence of phytane in the sediments. The presence of phytane and pristane in sediments from the Mackenzie River drainage basin has been reported by Peake et al. (1972) to be 180 and 250 $ng.g^{-1}$, respectively. The range of pristane found by the present study was 4 - 318 $ng.g^{-1}$, while the phytane range was 2 - 205 $ng.g^{-1}$. The range of the ratio of pristane to phytane was 1.09 - 6.75, with a mean of 1.69. Thus, suspended matter from the Mackenzie River may be a source of the phytane in the Beaufort Sea.

The concentrations of the alkanes found in the present study were compared to the results of other studies carried out in the Beaufort Sea, in other northern environments, and in other marine areas and were found to be comparable, indicating no sign of enrichment. The comparison is shown in Table 7.

TABLE 7. COMPARISON OF THE CONCENTRATIONS OF ALKANES FOUND IN SEDIMENTS IN THE SOUTHERN BEAUFORT SEA AND IN OTHER MARINE AREAS

Area		Total Alkanes ($ng.g^{-1}$)	Reference
Nearshore Zone of Southern Beaufort Sea	Mean	2,120	this study
	Range	195 - 4,213	
Abandoned Artificial Islands			Fowler and Hope, 1984.
Tarsiut East, 1981		3,500	
Tarsiut East, 1982		9,500	
Issungnak, 1981		5,900	
Issungnak, 1982		12,000	
West Atkinson		230	
Beaufort Sea Project 1974	Mean	84,600	Wong et al., 1976
	Range	18,400 - 163,600	
Beaufort Sea Project 1975	Mean	71,200	Wong et al., 1976
	Range	36,900 - 109,100	
Tarsiut N-44 1981	Mean	30,300	Thomas et al., 1982
	Range	1,300 - 80,300	
Tarsiut N-44 1982	Mean	78,800	Heath and Thomas, 1983
	Range	7,300 - 235,000	
Scotian Shelf 1973	Range	8 - 2,298	Keizer et al., 1978
Georges Bank 1977	Range	2,000 - 20,000	Boehm et al., 1980
Green-Duwamish River, 1978	Range	6,000 - 18,000,000	Hamilton et al., 1984
North Sea, 1984	Mean	1,100	Law and Fileman, 1985
	Range	400 - 2,000	

4.4.2 Polycyclic Aromatic Hydrocarbons. The widespread distribution of polycyclic aromatic hydrocarbons in the environment has been well documented (Hites et al., 1980a; Laflamme and Hites, 1978; Blumer and Youngblood, 1975; Youngblood and Blumer, 1975).

In this survey, sixteen specific PAH compounds (ranging from 2-ring to 6-ring compounds) were analyzed. The data were divided into groups according to the number of rings that each compound contained and according to their molecular weight. The summary is shown in Table 8, which also includes the analytical detection limit for each substance.

The data presented in Table 6 and Table 8 indicate that the concentrations of PAH present in sediments east of the Delta were higher than the concentrations found in sediments west of the Delta. To verify this observation, a one-way ANOVA followed by the LSD multiple comparison test was carried out. The results are shown in Table 9.

The source of the alkane nonacosane was attributed to terrestrial plant waxes (section 5.1). There was no correlation between the concentration of nonacosane and the concentrations of total PAH or any of the groups of PAH compounds having the same molecular weight. This indicated different sources of PAH's and alkanes.

Another factor that indicates a different source of PAH's from that of the alkanes has been suggested by Boehm and Farrington (1984) in their discussion of PAH data from the Georges Bank region. These authors observed that the

TABLE 8. SUMMARY OF PAH DATA IN THE NEARSHORE ZONE SEDIMENTS (all results are given in ng.g^{-1})

Station	Naphthalene (128)	Fluorene (166)	Phenanthrene/ anthracene (178)	Fluoranthene + pyrene (202)	benzanthracene+ chrysene (228)	benzofluoranthenes+ benzopyrenes+ perylene (252)	dibenzanthracene+ benzoperylene indenopyrene (276)	TOC (%)	nona cosane n-C29
4 (0-5 cm)	159	19	281	115	64	258	148	1.14	22
4 (15-20 cm)	74	16	235	99	57	203	133	1.08	8
5 (0-5 cm)	98	9	210	136	64	233	421	1.28	13
5 (15-20 cm)	133	5	174	102	61	147	129	1.16	12
6 (0-5 cm)	295	27	234	139	102	273	169	1.09	9
7 (0-5 cm)	113	N.D.	178	101	69	116	203	1.32	11
7 (15-20 cm)	79	9	229	86	46	194	123	0.95	13
8 (0-5 cm)	117	20	265	106	79	216	238	1.66	21
8 (15-20 cm)	54	43	205	111	58	2e7	206	1.37	18
9 (0-5 cm)	131	19	300	107	65	172	216	1.27	23
11 (0-5 cm)	106	N.D.	302	127	73	2e3	204	1.18	12
12 (0-5 cm)	28	14	183	73	49	190	137	1.25	20
13 (0-5 cm)	131	13	303	116	93	28e	151	1.35	58
14 (0-5 cm)	26	6	48	N.D.	3	47	N.D.	0.37	37
24 (0-5 cm)	39	N.D.	56	N.D.	20	48	N.D.	1.06	111
24 (15-20 cm)	71	10	150	69	55	121	27	0.99	124
25 (0-5 cm)	62	8	86	33	24	31	N.D.	1.00	156
25 (15-20 cm)	65	N.D.	57	28	N.D.	66	N.D.	1.01	126
26 (0-5 cm)	57	N.D.	63	N.D.	4	70	25	0.92	249
26 (15-20 cm)	57	N.D.	85	33	4	79	30	1.04	108
27 (0-5 cm)	11	N.D.	9	N.D.	N.D.	N.D.	N.D.	0.14	N.D.
28 (0-5 cm)	27	N.D.	8	N.D.	N.D.	N.D.	N.D.	0.08	7
29 (0-5 cm)	290	N.D.	227	73	42	193	115	1.03	21
30 (0-5 cm)	22	N.D.	19	N.D.	N.D.	N.D.	N.D.	0.17	43
31 (0-5 cm)	254	N.D.	233	78	37	22b	87	1.08	42
31 (15-20 cm)	110	N.D.	191	65	35	221	94	1.06	16
32 (0-5 cm)	301	10	173	101	44	140	127	1.11	15
33 (0-5 cm)	131	9	228	84	46	125	60	0.97	60
34 (0-5 cm)	110	N.D.	111	35	21	88	36	0.47	43
34 (15-20 cm)	68	N.D.	92	27	10	83	34	0.58	13
36 (0-5 cm)	44	N.D.	20	3	3	9	N.D.	0.21	5
37 (0-5 cm)	19	N.D.	36	6	1	8	N.D.	N.D.	N.D.

Detection limits: Naphthalene - 25
Fluorene - 4
Phenanthrene - 10
Anthracene - 1
Fluoranthene - 20
Pyrene - 20
Benzo(a)anthracene - 2.5
Chrysene - 2(
Benzo(e)Pyrene - 10
Perylene - 20 (Benzo(b)Fluoranthene co-elutes)
Benzo(k)fluoranthene - 20
Benzo(a)pyrene - 4
Dibenzo(ah)anthracene - 2.5
Benzo(ghi)Perylene - 25
Indeno (123 cd)Pyrene - 25

All concentrations are in ng.g^{-1}

TABLE 9. ONE WAY ANOVA AND LEAST SIGNIFICANT DIFFERENCE MULTIPLE COMPARISON TEST FOR HYDROCARBON DATA FROM GROUPS 1 - 4

Variable	Groups Compared 1/2	1/3	1/4	2/3	2/4	3/4	Rank of Mean Lowest		Highest	
Total PAH	*	*	*	*			4	3	1	2
n-C_{29}	*	*	*	*			2	1	4	3
Total Alkane	*	*	*	*	*		2	1	4	3

Note: * - indicates a significant difference between the two groups at the 0.05 level of probability)
1 - east of Delta, 0 - 5 cm, 81 - 100 % silt/clay
2 - east of Delta, 15 - 20 cm, 81 - 100 % silt/clay
3 - west of Delta, 0 - 5 cm, 81 - 100 % silt/clay
4 - west of Delta, 15 - 20 cm, 81 - 100 % silt/clay
- ranks not sharing an underscore were significantly different at $p \leq 0.05$

relationship between the alkane nonacosane and total organic carbon was significantly positive (at the 0.05 level of probability). Since the source of the alkane nonacosane was terrigenous plant material, the authors deduced that the source of organic carbon was also from terrigenous material. They correlated the concentrations of the PAH's phenanthrene / anthracene and total organic carbon, obtained a significantly positive correlation, and concluded that the PAH's in the Grand Banks region originate from terrigenous sources. In the Beaufort Sea Nearshore Zone, the correlation between the alkane nonacosane and total organic carbon was not significant at the 0.05 level of probability, and the correlation between phenanthrene/anthracene and nonacosane was significantly negative (at the 0.05 level of probability), indicating that the source of PAH's in the Beaufort Sea is not terrigenous material.

Polycyclic aromatic hydrocarbons can be introduced to the environment from a variety of sources. The three most important sources identified by Hites et al. (1980) are:

a) direct deposition of petroleum (characterized by a PAH mixture which is deficient in unsubstituted species);

b) combustion (the PAH mixture is characterized by homologs which decrease in abundance as the degree of alkyl substitution increases. This type of mixture results from both natural (forest fire) and anthropogenic (fossil fuel) combustion); and,

c) in situ aromatization of naturally occurring precursors such as plant terpenes (the PAH mixture is less complex and contains compounds which are directly related to the skeletal structures of the precursors. Examples of naturally derived PAHs are perylene, retene, and certain alkyl chrysene and picene species).

No attempt was made in this study to quantify and differentiate between alkylated and non-alkylated PAH's, and therefore, no specific source of PAH's could be identified. The large number of forest fires in the area located south of the Mackenzie River Delta could be a potential source of PAH's in the Beaufort Sea. This material could enter the Beaufort Sea as airborne particles or as suspended material transported by the Mackenzie River.

The PAH concentrations found in this study were compared to data obtained from other areas in North America and in the Beaufort Sea. This comparison is presented in Table 10 and it

suggests that no enrichment trend in the concentration of PAH's has occurred in the past in the Beaufort Sea.

TABLE 10. COMPARISON OF PAH DISTRIBUTION BETWEEN VARIOUS LOCATIONS IN NORTH AMERICA AND IN THE BEAUFORT SEA (all concentrations are given in $ng.g^{-1}$)

Location	Concentration of PAH - Compound $C_{14}H_{10}$	$C_{16}H_{10}$	$C_{16}H_{10}$	$C_{18}H_{12}$	$C_{20}H_{12}$	Total	Reference
Charles River(1)	5,000	15,000	13,000	21,000	33,000	87,000	Hites et al., 1980b
New York Bight(1a)	740	1,200	1,300	890	1,700	5,800	
Buzzards Bay(2)	53	140	120	200	380	870	
Alaska(3)	67	4	8	23	11	110	
Alaska(4)	2.5	0.6	0.6	1.4	0.6	5.7	
Beaufort Sea(5)	302	82	45	73	102	604	this study
Beaufort Sea(6)	303	61	55	185	119	723	this study
Beaufort Sea(7)	Sum of 16 unsubstituted			Range 20 - 1237			this study
Beaufort Sea	Sum of benzanthracene, chrysene, pyrene, perylene, and certain other isomers			Range 236 - 984 (wet weight)			Wong et al., 1976
Beaufort Sea	Sum of benzanthracene, chrysene, pyrene, perylene, and certain other isomers			Range 97 - 1341 (wet weight)			Wong et al., 1976
Beaufort Sea	Benz(a)pyrene			Range 0.2 - 33			Stich and Dunn, 1980
Beaufort Sea	Total Resolved PAH			Range 68 - 1856			Erickson et al., 1982
Beaufort Sea (Abandoned Artificial Island)	Total unsubstituted PAH			Range 1,560 - 5,270			Fowler and Hope, 1984
	Total alkylated PAH			Range 560 - 2,810			

1 - Boston, Massachusetts. Anoxic sediment, considered highly polluted by PAH's.
1a - New York. Considered polluted from various discharges.
2 - Considered pristene, potential source of PAH's is fossil fuel combustion.
3 - Intertidal sediment, collected from the vicinity of a natural seep.
4 - Intertidal sediment, collected in an area considered free from antropogenic or oil contamination.
5 - East of the Mackenzie Delta, influenced by the Mackenzie River discharge.
6 - West of the Mackenzie Delta, small influence by the Mackenzie River discharge.
7 - Summary of data from this survey.

5.0 CONCLUSIONS

1. There was no change in the sediment particle size distribution in the area east of the Mackenzie River Delta over time, indicating a uniform source of sediment input in the past 50 - 66 years. In this area, the finer sediment was deposited close to the mouth of the Delta, and the coarser sediment was found farther away from the Delta. In the Herschel Basin, the distribution of the sediments was controlled by the bottom morphology. The fine grained sediment was found in the center of the depositional basin, and the coarse grained sediment was found on the margins of the basin.

2. A significant positive correlation was found between silt and all metals when the data were pooled together, but a significant negative correlation (or no correlation) was observed when the data were divided according to specific locations. A significant positive correlation was observed between clay and all metals when the data were pooled and when they were divided according to specific locations.

3. The concentrations of four metals (Ba, Ni, Zn, and Cd) were significantly higher at stations located to the east of the Mackenzie River Delta. Iron was significantly higher in the 15 - 20 cm core section in samples collected in the Herschel Basin (west of the Mackenzie River Delta) than in any other area. In addition, the concentrations of this metal were significantly higher in the Herschel Basin area in the 15 - 20 cm core section than in the 0-5 cm core

section. This anomaly was attributed to changes over time in the input of terrestrial and marine material to this area.

4. Terrigenous detrital material originating in vascular plant waxes was presumed to be the source of the alkanes found in this study. There was also an indication of an input of hydrocarbons from marine detrital material.

5. The source of the PAH's in the Beaufort Sea does not appear to be from terrigenous detrital material. The possible sources of the PAH's in this area are petroleum, combustion of fossil fuels, forest fires, and aromatization of naturally occurring precursors.

6.0 RECOMMENDATIONS.

1. Site(s) specific studies where industrial activities will take place should continue to be undertaken to quantify the natural variability in the distribution of metals in the Nearshore Zone of the southern Beaufort Sea. The studies should focus on the Herschel Basin and on an area located in the vicinity of North Point (east of the Mackenzie River Delta).

2. A study of hydrocarbons, with emphasis on polycyclic aromatic hydrocarbons, should be undertaken in the Beaufort Sea area to distinguish between, and quantify, natural and anthropogenic hydrocarbons. This study should focus on the same areas that were suggested in Recommendation 1.

3. A well formulated quality control program should be carried out in association with each future monitoring survey.

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APPENDIX A

GEOGRAPHICAL CO-ORDINATES OF STATIONS

AND

OTHER DETAILS OF SAMPLING

Geographical Co-ordinates of Stations and Details of Sampling

Sample	No.	Date	Geographical Co-ordinates (Lat. oN)	(Long. oW)	Depth (m)	Core Length (cm)
B.S.O.	1-1	09/07/84	69:34.60'	133:12.75'	4	12
B.S.O.	2-1	09/07/84	69:35.64'	133:10.89'	4	11
B.S.O.	3-1	09/07/84	69:39.46'	133:13.31'	5	14
	3-2	09/07/84	69:39.46'	133:13.31'	5	14
B.S.O.	4-1	09/07/84	69:46.89'	133:19.54'	10.8	20
	4-2	09/07/84	69:46.89'	133:19.54'	10.8	10
	4-3	09/07/84	69:46.89'	133:19.54'	10.8	10
B.S.O.	5-1	09/07/84	69:49.57'	133:30.91'	10	48
	5-2	09/07/84	69:49.57'	133:30.91'	10	35
B.S.O.	6-1	09/07/84	69:51.80'	133:30.91'	10.7	14
B.S.O.	7-1	09/07/84	69:53.94'	134:07.75'	11	20
	7-2	09/07/84	69:53.94'	134:07.75'	11	27
B.S.O.	8-1	10/07/84	69:53.85'	130:26.93'	10	15
	8-2	10/07/84	69:53.85'	134:26.93'	10	20.5
B.S.O.	9-1	10/07/84	69:50.82'	130:48.21'	10.3	8
	9-2	10/07/84	69:50.82'	134:48.21'	10.3	5
B.S.O.	10-1	10/07/84	69:48.09'	134:45.07'	8	Grab
B.S.O.	11-1	10/07/84	69:43.46'	134:42.44'	6.0	11.3
	11-2	10/07/84	69:43.46'	134:42.44'	6.0	10.0
B.S.O.	12-1	10/07/84	69:49.11'	135:02.51'	6	9.0
	12-2	10/07/84	69:49.11'	135:02.51'	6.0	10.0
B.S.O.	13-1	12/07/84	69:06.53	137:52.65'	20	18
	13-2	12/07/84	69:06.53	136:52.65'	20	15
B.S.O.	14-1	12/07/84	69:06.40'	137:58.08'	10	5
	14-2	12/07/84	69:06.40'	137:58.08'	10	8
B.S.O.	15-1	12/07/84	69:22.97'	138:41.22'	13.7	16
	15-2	12/07/84	69:22.97'	138:41.22'	13.7	14
B.S.O.	16-1	12/07/84	69:25.75'	138:56.33'	11	24
	16-2	12/07/84	69:25.75'	138:56.33'	11	14

Sample Location and No.		Date	Geographical Co-ordinates (Lat. oN)	(Long. oW)	Depth (m)	Core Length (cm)
B.S.O.	17-2	12/07/84	69:26.35	138:54.64	11.5	9
B.S.O.	18-1	12/07/84	69:27.75	138:52.78	51	18
	18-2	12/07/84	69:27.75	138:52.78	51	15
	18-3	12/07/84	69:27.75	138:52.78	51	15
B.S.O.	19-1	12/07/84	69:28.85	138:47.60	34	25
	19-2	12/07/84	69:28.85	138:47.60	34	24.5
	19-3	12/07/84	69:28.85	138:47.60	34	23
B.S.O.	20-1	12/07/84	69:29.69	138:44.78	15	40
	20-2	12/07/84	69:29.69	138:44.78	15	45
B.S.O.	21-1	12/07/84	69:31.44	138:43.85	28	53
	21-2	12/07/84	69:31.83	138:43.85	28	47
B.S.O.	22-1	12/07/84	69:32.21	138:51.12	45	53
	22-2	12/07/84	69:32.20	138:51.12	45	48
B.S.O.	23-1	12/07/84	69:31.83	138:54.92	45	53
	23-2	12/07/84	69:31.83	138:54.92	45	48
B.S.O.	24-2	17/07/84	69:33.90	138:54.85	10	20
B.S.O.	25-1	17/07/84	69:32.90	138:56.65	15	32
	25-2	17/07/84	69:32.90	138:56.65	15	27
B.S.O.	26-1	17/07/84	69:31.65	138:59.50	16	48
	26-2	17/07/84	69:31.65	138:59.50	16	47
B.S.O.	27	19/07/84	69:49.73	132:56.90	10	Grab
B.S.O.	28	19/07/84	69:53.25	132:55.60	10	Grab
B.S.O.	29-1	19/07/84	69:54.05	132:50.96	11	18
	29-2	19/07/84	69:54.05	132:50.96	11	19
B.S.O.	30	19/07/84	69:53.95	132:45.61	10	Grab
B.S.O.	31-1	19/07/84	69:49.71	132:24.48	10	28
	31-2	19/07/84	69:49.71	132:24.48	10	30
B.S.O.	32-1	19/07/84	69:53.75	132:11.45	10.5	16
	32-2	19/07/85	69:53.75	132:11.45	10.5	18.5

Sample Location and No.		Date	Geographical Co-ordinates (Lat. oN)	(Long. oW)	Depth (m)	Core Length (cm)
B.S.O.	33-1	19/07/84	69:52.80'	131:48.00'	10	16
	33-2	19/07/84	69:52.80'	131:48.00'	10	16
B.S.O.	34-1	19/07/84	69:56.80'	131:31.50'	10	29.5
	34-2	19/07/84	69:56.80'	121:31.50'	10	30
B.S.O.	36	19/07/84	70:05.80'	131:01.00'	8	Grab
B.S.O.	37	19/07/84	70:11.85'	130:50.80'	10	Grab
B.S.O.	38	19/07/84	70:15.85'	130:34.70'	10.5	Grab
B.S.O.	39	19/07/84	70:20.02'	130:18.40'	10	Grab
B.S.O.	40-1	19/07/84	70:16.70'	130:00.00'	9.5	16
	40-2	19/07/84	70:16.70'	130:00.00'	9.5	17
B.S.O.	41	19/07/84	70:06.25'	130:02.00'	3	Grab
B.S.O.	42-1	19/07/84	70:08.68'	130:04.55'	5	15
	42-2	19/07/84	70:08.68'	130:04.55'	5	15.5
B.S.O.	43	19/07/84	70:09.50'	130:13.60'	4	Grab

APPENDIX B

ANALYTICAL METHODS AND RESULTS OF QUALITY CONTROL PROGRAM FOR METALS AND HYDROCARBONS

Sediment Grain Size. Twenty millilitres of NaOCl were added to 20 g of air dried sediment in a 250 ml centrifuge bottle. If excessive frothing developed, a few drops of amyl alcohol or Anti-Foam A Spray were added. After adding 60 ml of NaOCl, the sample was gently mixed, heated to 80°C in a water bath for 15 minutes, allowed to cool to room temperature, and centrifuged for 10 minutes at 2400 rpm. The liquid portion of the sample was decanted and discarded. Addition of the NaOCl, centrifugation, and decanting of the liquid portion of the sample were repeated until the supernate was yellow or pink (but not brown). Eighty millilitres of distilled water were added to the sample, centrifuged and decanted. This was repeated, until the sediment dispersed and could not be separated from the liquid portion by centrifugation. This procedure was carried out to break down the organic matter that would have interfered with the following short pipette method for particle size analysis.

Fifty millilitres of sodium pyrophosphate were added to the 250 ml bottle, and the solution was allowed to stand for 10 minutes. The sample was then transferred to an electric mixer, distilled water was added, and the contents were mixed for 10 minutes. The suspension was then quantitatively transferred into a one liter sedimentation cylinder, and made up to the one liter mark. A "blank" solution containing 50 ml of sodium pyrophosphate made up to one liter with distilled water was analysed along with the sediment samples.

The sample was stirred for 45 seconds, and at specific

time intervals sub-samples were withdrawn and used for the determination of sand, silt, and clay percentages, which was carried by the method described by Duncan and Lahaie (1979).

Total Organic Carbon. Dried, pulverized sediment (0.5 g) was weighed into a 100 ml beaker, and 15 ml of concentrated HCl were added. The solution was boiled for 15 minutes to decompose carbonates. The solution was then cooled to room temperature, and filtered through a Leco filtering crucible designed for total organic carbon analysis. The residue in the crucible was washed with hot water and oven dried at 105°C for three hours.

One unit of iron chips, one-half unit of tin metal accelerator and one copper ring accelerator were added to each crucible. Carbon analysis was carried out using a Leco Induction Furnace. The evolved gas was swept into a Dietert volumetric CO_2 analyzer calibrated for percent carbon. Leco Certified Standards and a blank were run with every ten samples.

Metals-Barium, Chromium, Copper, Iron, Nickel, Zinc, Cadmium, and Lead. Two digestion procedures were carried out on each sample: a nitric-perchloric digestion and an $HF-HNO_3-HClO_4-HCl$ digestion.

Nitric-perchloric digestion. Five grams of wet sample were weighed into a 150 ml Pyrex beaker and 5 to 7 ml of HNO_3 were added. The beaker was then covered with a watch glass. The solution was heated for two hours, then cooled, and 3 to 5 ml

of $HClO_4$ were added. The solution was digested to evolution of white fumes of $HClO_4$, allowed to cool and 10 ml of distilled water were added. The solution was heated to dissolve any salts, then cooled to room temperature, transferred to a 50 ml volumetric flask, and diluted to the mark with distilled water. Analysis was performed utilizing the methods outlined in the following section.

HF-HNO_3-$HClO_4$-HCl Digestion. 0.5 g of air dried sediment sample was weighed into a teflon beaker and digested in the following manner:

a) 10 ml HF were added, slowly heated to dryness, and cooled;

b) then 5 ml HF and 5 ml HNO_3 were added, heated to dryness, and cooled;

c) then 5 ml HCl, 5 ml HNO_3, 5 ml HF were added, heated to dryness, and cooled;

d) then 5 ml HNO_3 and 5 ml $HClO_4$ were added, heated until dense white fumes of $HClO_4$ evolved, and heated further until only 1-2 ml $HClO_4$ remained;

e) the solution was allowed to cool, 20 ml distilled water and 2 ml HCl were added and the resulting solution boiled gently to dissolve salts.

The solution was then transferred to a 50 ml volumetric flask and diluted to the mark with distilled water. The analysis was performed utilizing the methods outlined in the following sections.

Inductively Coupled Plasma and Atomic Absorption Analysis. The Inductively Coupled Plasma (ICP) analysis was performed on the 'Total Acid Digest' solution (section 3.2.3.2). The ICP analytical wavelengths used were:

Barium	455.4 nm
Chromium	276.7 nm
Copper	324.7 nm
Iron	259.9 nm
Nickel	231.6 nm
Zinc	206.1 nm

The instrument was calibrated using standard certified solutions prepared from pure metals or pure metal salts. Calibration was checked after every ten analyses. Each sample was analysed in triplicate and the results were averaged. Results of a quality control program, including data from analysis of blanks and Certified Reference Materials, are presented in Appendix B.

Cadmium was determined by Graphite Furnace Atomic Absorption Spectrophotometry using the $HNO_3/HClO_4$ solution. Instrumental operating conditions were as follows:

Wavelength	222.8	nm
Lamp Current	6	mA
Slit Width	0.7	nm
Volume Injected	50	microliters

Drying Cycle	100°C	for 30 sec, ramp 20 sec
Charring Cycle	400°C	for 30 sec, ramp 20 sec
Atomizing Cycle	1500°C	for 8 sec

Each sample was analysed in triplicate and the results were averaged.

Lead was analyzed using Background Corrected Flame Atomic Absorption Spectrophotometry. Copper, zinc, and chromium were also analyzed using this technique as part of the quality control program. Analyses of lead, copper, and zinc were carried out using $HNO_3/HClO_4$ solution, while chromium was determined using the 'HF-HNO_3-$HClO_4$-HCl solution. The instrumental conditions were as follows:

	Copper	Chromium	Lead	Zinc
Wavelength	324.7 nm	357.9 nm	283.3 nm	213.9 nm
Lamp Current	4 mA	7 mA	5 mA	5 mA
Slit Width	0.5 nm	0.2 nm	0.5 nm	1.0 nm
Flame Conditions	oxidizing	reducing	oxidizing	oxidizing

Each solution was analyzed in triplicate. Each batch of solutions was aspirated in sequence, and this was repeated twice. The instrument was calibrated with standard solutions prepared from pure metals or from pure metal salts.

Mercury. Mercury was analysed in $HNO_3/HClO_4$ solutions. To each solution, 10 drops of 20 % (w/v) $SnCl_2$ solution were added. The

sample vessel was then connected to a mercury monitor, and elemental mercury was passed through the monitor using nitrogen gas as a carrier. Digestion blanks and sample solutions were analysed in triplicate and the results were averaged. The calibration curve was prepared by plotting recorder peak height versus micrograms of mercury in standard solutions.

Organic Constituents - N-Alkanes and Polycyclic Aromatic Hydrocarbons.

Extraction and Clean-up - N-Alkanes. Between 10 and 30 g of air dried sample were subjected to an extraction process using dichloromethane (DCM). Cleanup was accomplished by passing the extracts through a column containing sodium sulphate, followed by a silica gel column; n-decyl benzene was then added as an Internal Standard (IS) for gas chromatographic (GC) analysis.

Extraction and Clean-up - Polycyclic Aromatic Hydrocarbons. Between 10 and 30 g of air dried sample were subjected to a soxhlet extraction process using DCM. The extract was reconstituted in hexane and cleanup was carried out using a sodium sulphate/activated alumina column prior to analysis by high performance liquid chromatography (HPLC). The procedure is described in detail in Appendix C.

Gas Chromatography - N-Alkanes. Sample aliquots were injected on the GC column and the resulting trace was recorded on a chart recorder. The internal standard method was used for

quantification by obtaining the ratio of the n-alkanes peak areas to that of the I.S. The GC operating conditions were as follows:

Column Type

Column	-	15 m x 0.4 mm I.D.
Liquid Phase	-	DB-1 (durabond), thickness 0.25 um

Gases

Inlet	-	carrier gas: nitrogen column flow: 2 $ml.min^{-1}$ splitless injection
Detector	-	makeup (N_2) - 25 $ml.min^{-1}$ Air - 400 $ml.min^{-1}$ Hydrogen - 30 $ml.min^{-1}$

Temperatures

Column Temp.	-	Initial Temp. = 50°C Initial hold time: 1.5 min.

Step #	Final Temp	Rate	Hold Time
1	100°C	$10°C.min^{-1}$	0 min
2	265°C	$4°C.min^{-1}$	0 min
3	290°C	$25°C.min^{-1}$	3.25 min

Injector Temp - 290°C

Detector Temp - 310°C

Liquid Chromatography (LC) - Polycyclic Aromatic Hydrocarbons Analysis. An aliquot of 20 to 100 microliters was injected onto the LC column. Gradient parameters for the LC analysis were as follows:

a) 50 % acetonitrile in water, isocratic hold for 5 minutes;

b) linear gradient from 50 % acetonitrile to 100 % acetonitrile in 3 minutes; and,

c) final isocratic hold at 100 % acetonitrile for 20 minutes.

The detection for the LC analysis was both UV and Fluorescence (sequentially):

UV at 280 nm;
Fluorescence at 254 nm excitation /395 emission; and,
280 nm excitation /395 emission.

The column used was a Waters Radial-PAK, PAH< 10 micron particle size 5 mm ID x 10 cm. Results were calculated based on response factor comparison to external standards. Identification was based on retention time. Quantification was carried out by an external calculation method. For each of the compounds of interest, a calibration standard solution at three different concentrations was prepared by dilution of the stock standards with the mobile phase mixture. The lowest concentration of standard solution was at or slightly above the method detection limit. The other two concentrations were at levels corresponding to the expected ranges of the real samples. Injections of the standards provided retention times for peak identification and peak area for calculating the response factor for each compound of interest. The standard deviation of the response factor for each compound over the concentration range of the standards was less than 10 %. The response factor was verified by at least two injections of standards. The calculation was as follows:

$$RF_i = \frac{C_i}{A_i}$$

$$[i] = \frac{RF_i C_i B}{AD}$$

where:
- A - volume of injection (ul)
- B - volume of final extract (ul)
- D - weight of sample extracted (g)
- i - individual compound
- C_i - nanograms injected
- A_i - area of peak (i)
- [ ] - concentration ($ng.g^{-1}$)
- RF - response factor

If the peak area of the compound of interest exceeded the working range of the standards, the extract was diluted and analysed. The complexity of the extracts from the sediment samples warranted a confirmation step, which was performed by Gas Chromatography/Mass Spectrometry (GC/MS).

Gas Chromatography/Mass Spectrometry Confirmation - Polycyclic Aromatic Hydrocarbons. A GC/MS analysis was carried out on one solution from the PAH extraction procedure to confirm the identity of the PAH's. The analysis was carried out on a Finnigan GC/MS under the following instrumental conditions:

Mode	-	EI @ 70 eV energy
Manifold	-	80°C
Separator	-	220°C
Scan Range	-	40 - 450 AMU in 1 sec.
Column	-	Fused silica capillary SPB-5, 0.25 mm ID x 30 M Splitless injection
Program	-	30°C - 280 °C at $4^{\circ}C.min^{-1}$ and hold at 280°C for 10 min.

Computer search for contaminant identity was performed against the National Bureau of Standards library. Description and results of the quality control program for n-alkanes and PAH's are presented in Appendix C.

TRACE METALS QUALITY CONTROL: Digestion Blanks

ELEMENTS	Ba	Cr	Cu	Fe	Ni	Zn	Hg	Cd	Pb
Number of Blanks	14	14	14	14	14	14	17	17	17
Maximum Blank	1.5	3.2	3.0	0.005	2.0	4.9	0.002	<0.016	<1.7
Minimum Blanks	0.3	0.7	1.2	0.002	1.4	1.8	<0.002	<0.016	<1.7
Average Blanks	1.0	2.2	1.8	0.003	1.8	3.0	<0.002	0.016	<1.7

QUALITY CONTROL DATA: Results on Certified Marine Sediment Reference Material NRC BCSS-1 expressed in micrograms per gram, iron in percent

ELEMENT	Ba	Cr	Cu	Fe	Ni	Zn	Hg	Cd	Pb
DIGESTION	AD	AD	AD	AD	AD	AD	NP	NP	NP
ANALYSIS	ICP	ICP	ICP	ICP	ICP	ICP	Hg-M	AA-GF	AA-F
Certified Value	--	123. +14.	18.5 +2.7	3.28 +0.10	55.3 +3.6	119. +12.	0.129 +0.012	0.25 +0.04	22.7 +3.4
Results Obtained	289.	103.	17.	3.18	57.	104.	0.115	0.30	23.
	283.	96.	16.	3.12	60.	98.	0.107	0.25	22.
	293.	98.	17.	3.28	55.	102.	0.140	0.30	24.
	304.	96.	21.	3.04	57.	107.	0.135	0.25	23.
	291.	95.	17.	3.19	53.	111.	0.140	0.23	20.
	293.	98.	19.	3.20	55.	104.	0.135	0.20	22.
	--	--	--	--	--	--	0.145	0.25	19.
Average	291.	97.	18.0	31.4	56.1	104.	0.131	0.26	21.7
Average Percent Recovery	--	78.9%	97.3%	95.7%	101.4%	87.4%	101.5%	104.0%	95.5%
Precision (+- 1.SD)	7.	3.	1.7	0.10	2.2	4.0	0.013	0.04	1.7
Coefficient of Variation	2.40%	3.09%	9,44%	3.18%	3.92%	3.85%	9,92%	15.4%	7.83%
Accuracy (+- 1.SD)	--	28.	1.8	0.18	2.4	16.2	0.014	0.04	3.9

AD = Digestion, HF, HCl, HNO_3, $HCLO_4$
NP = HNO_3, $HClO_4$

ICP = Plasma Analysis
AA-F = Flame Atomic Absorption
Hg-M = Mercury Monitor
AA-GF = Graphite Furnace Atomic Absorption

QUALITY CONTROL DATA: Results on Certified Marine Sediment Reference Material NRC BCSS-1 expressed in micrograms per gram, iron in percent

ELEMENT	Ba	Cr	Cu	Fe	Ni	Zn	Hg	Cd	Pb
DIGESTION	AD	AD	AD	AD	AD	AD	NP	NP	NP
ANALYSIS	ICP	ICP	ICP	ICP	ICP	ICP	Hg-M	AA-GF	AA-F
Certified Value	--	71	25.1	3.05	29.5	191.	0.171	0.59	34.0
		11.	3.8	0.17	2.7	17.	0.014	0.10	6.1
Results Obtained	266.	62.	24.	3.00	26.	172.	0.165	0.65	33.
	269.	53.	25.	2.83	29.	176.	0.160	0.55	31.
	263.	58.	27.	2.75	27.	180.	0.185	0.64	32.
	272.	57.	27.	2.96	30.	180.	0.190	0.61	30.
	278.	52.	27.	2.90	32.	173.	0.155	0.60	30.
	--	--	--	--	--	--	0.160	0.63	28.
	--	--	--	--	--	--	0.180	0.54	28.
	--	--	--	--	--	--	0.165	0.60	28.
Average	270.	56.4	26.0	2.90	28.8	176.	0.170	0.60	30.
Average Percent Recovery	--	79.4%	103.5%	95.1%	97.6%	92.1%	99.4%	101.7%	88.2%
Precision (+- 1.SD)	6.	4.0	1.4	0.09	2.4	3.4	0.013	0.04	1.9
Coefficient of Variation	2.22%	7.09%	5.38%	3.10%	8.33%	1.93%	7.65%	6.67%	6.33%
Average (+- 1.SD)	--	16.8	3.5	0.19	5.0	16.4	0.013	0.04	4.7

AD = Digestion, HF, HCl, HNO_3, $HCLO_4$
NP = HNO_3, $HClO_4$

ICP = Plasma Analysis
AA-F = Flame Atomic Absorption
Hg-M = Mercury Monitor
AA-GF = Graphite Furnace Atomic Absorption

QUALITY CONTROL DATA: Results on Certified Geological Material GRX-6 (U.S. G.S.) expressed in micrograms per gram, iron in percent

ELEMENT	Ba	Cr	Cu	Fe	Ni	Zn
DIGESTION	AD	AD	AD	AD	AD	AD
ANALYSIS	ICP	ICP	ICP	ICP	ICP	ICP
Certified Value:	1100.	96.	105.	5.47	22.	120.
Results Obtained:	1203.	92.	66.	5.32	22.	107.
	1251.	86.	65.	5.33	25.	123.
	1215.	86.	71.	5.07	27.	121.
	1260.	84.	66.	5.35	25.	125.
	1289.	86.	67.	5.46	27.	123.
Average	1243.	84.4	66.8	5.39	25.2	120.
Average Percent Recovery	113%	87.9%	63.6%	98.5%	114.5%	100.0%
Precision (+/- 1.SD)	34.	4.7	2.1	0.07	2.0	7.3
Coefficient of Variation	2.73%	5.56%	3.14%	1.29%	7.93%	6.08%
Accuracy (+/-1.SD)	164.	13.8	42.	0.23	4.1	7.3

AD = Digestion, HF, HCl, HNO_3, $HClO_4$
ICP = Plasma Analysis

QUALITY CONTROL: Sample Replicates
Results expressed in micrograms per gram, iron in percent

ELEMENT	Ba	Cr	Cu	Fe	Ni	Zn
DIGESTION	AD	AD	AD	AD	AD	AD
ANALYSIS	ICP	ICP	ICP	ICP	ICP	ICP
Results Obtained:						
B.S.O. 4-2 (0.5 cm)	835.	85.	33.	3.59	43.	138.
	834.	82.	30.	3.64	44.	144.
	846.	74.	30.	3.64	42.	135.
	835.	77.	36.	3.58	45.	128.
	854.	75.	33.	3.66	44.	133.
Average	841.	79.	32.	3.62	44.	136.
Precision(+/-1.SD)	9.0	4.7	2.5	0.036	1.1	5.9
Coefficient of Variation	1.07%	5.53%	7.81%	0.99%	2.50%	4.34%
B.S.O. 23-1 (0-5 cm)	741.	90.	31.	3.75	35.	131.
	738.	88.	31.	3.76	43.	130.
	727.	85.	31.	3.73	44.	121.
	732.	87.	33.	3.72	46.	121.
	745.	86.	32.	3.81	43.	121.
Average	736.	87.	32.	3.75	42.	125.
Precision(+/-1.SD)	7.2	1.9	0.9	0.035	4.2	5.2
Coefficient of Variation	0.98%	2.18%	2.81%	0.93%	10.0%	4.16%
B.S.O. 34-2 (0-5 cm)	754.	53.	20.	2.52	30.	80.
	767.	51.	20.	2.40	33.	86.
	729.	52.	20.	2.51	29.	92.
	758.	61.	23.	2.58	33.	93.
	757.	57.	26.	2.57	33.	89.
Average	753.	55.	22.	2.52	32.	88.
Precision(+/-1.SD)	14.2	4.1	2.7	0.066	1.9	4.7
Coefficient of Variaiton	1.89%	7.45%	12.3%	2.62%	5.93%	5.34%

AD = HF, HCl, HNO_3, $HClO_4$
ICP = Plasma Analysis

QUALITY CONTROL: Sample Replicates
Results expressed in micrograms per gram, iron in percent

ELEMENT		Hg	Cd	Pb
DIGESTION		NP	NP	NP
ANALYSIS		Hg-M	AA-GF	AA-F
Results Obtained:				
B.S.O. 4-1 (0.5 cm)		0.045	0.32	25.2
		0.068	0.20	17.7
		0.067	0.20	17.5
		0.082	0.19	15.6
Average		0.066	0.23	19.0
Precision(+/-1.SD)		0.015	0.062	4.2
Coefficient of Variation	1.07%	22.7%	26.9%	22.1%
B.S.O. 14-2 (0-5 cm)		0.022	0.11	6.46
		0.023	0.12	6.50
		0.030	0.11	5.25
		0.021	0.09	5.76
		0.024	0.09	5.64
Average		0.024	0.104	5.92
Precision(+/-1.SD)		0.004	0.013	0.54
Coefficient of Variation	0.98%	16.7%	12.5%	9,12%
B.S.O. 30 Grab		0.002	0.024	1.45
		0.002	0.025	1.85
		0.002	0.013	1.46
		0.002	0.012	1.34
		0.002	0.012	1.34
Average		0.001	0.017	1.49
Precision(+/-1.SD)		-----	0.007	0.21
Coefficient of Variation		-----	41.2%	14.1%

NP = HNO_3, $HClO_4$ digestion
AA-GF = Graphite Furnace Atomic Absorption
AA-F = Flame Atomic Absorption
Hg-M = Mercury Monitor

Concentration of aromatic hydrocarbons (ng/g dry weight) found in Homogenized Reference Sediment: x = mean, RSD = Relative Standard Deviation of the Mean (100 SD/x), n = number of analyses.

Aromatic Hydrocarbon	X (n = 6)	RSD
Fluorene	30	28
Phenanthrene	330	28
Anthracene	57	26
Fluoranthene	570	23
Pyrene	760	21
Benzo (a) anthracene	440	23
Chrysene	270	20
Benzo (e) pyrene	150	26
Benzo (a) pyrene	170	33
Perylene	36	36

POLYCYCLIC AROMATIC HYDROCARBONS PERCENT RECOVERIES OF SPIKED SEDIMENTS

SAMPLE IDENTIFICATION	NAPHTHALENE	FLUORENE	PHENANTHRENE	ANTHRACENE	FLUORANTHENE	PYRENE	BENZO (a) ANTHRACENE	CHRYSENE	BENZO (e) PYRENE	PERYLENE*	BENZO (b) FLUORANTHENE*	BENZO (k) FLUORANTHENE	BENZO (a) PYRENE	DIBENZO (ah) ANTHRACENE	BPN (ghi) PERYLENE	INDENO (123 cd) PYRENE
Spike #1	72	72	73	91	93	96	92	97	94	94		96	61	100	85	91
Spike #2	68	102	71	116	75	73	65	78	75	76		76	48	70	70	76
Spike #3	88	75	80	125	84	87	84	92	87	94		85	54	76	94	74
Spike #4	63	76	74	78	82	81	81	88	82	81		80	52	65	70	67
Spike #5	107	79	71	91	72	75	69	72	64	69		65	62	66	71	68
Spike #6	101	78	75	72	71	72	72	68	67	69		62	59	70	69	64
Mean (x)	83	80	74	95	80	81	77	83	78	81		77	51	75	77	73
Standard Deviation	18	10	3	20	8	9	10	12	12	11		13	5	13	10	10
Relative Standard Deviation (RSD)	2	13	4	21	10	11	13	14	15	14		17	9	17	13	14

*NOTE: Perylene and Benzo (b) Fluoranthene co-elute and are indistinguisable. The perylene result is a total of the two compounds.

APPENDIX C

RESULTS OF TEST FOR NORMALITY

EAST OF MACKENZIE DELTA SURFACE (0-5 cm)

Variable	Mean	s^2	S.D.	Skewness	z
2	47.13	23.48	4.85	.33	.57
3	51.91	31.00	5.57	-.72	-1.24
4	1.17	.03	.17	1.06	1.83
5	846.13	1092.98	33.06	.70	1.21
6	79.20	30.60	5.53	-.45	-0.78
7	29.67	9.52	3.09	.50	.86
8	3.5	.03	.17	-.38	-.66
9	41.33	7.81	2.79	-.49	-.84
10	135.33	113.24	10.64	.07	.12
11	.07	.00	---	.48	.83
12	.33	.02	.14	2.15	3.71
13	16.99	2.66	1.63	-.18	-.31

EAST OF MACKENZIE DELTA BOTTOM (15-20 cm)

Variable	Mean	s^2	S.D.	Skewness	z
2	46.35	146.28	12.09	.14	.14
3	52.8	173.65	13.18	-.37	-.37
4	1.14	.03	.17	.73	.72
5	859.25	820.92	28.65	1.94	1.92
6	79.25	54.92	7.41	-.89	-0.88
7	28.5	6.33	2.52	-1.13	-1.12
8	3.56	.04	.20	.83	.826
9	42.75	12.25	3.50	2.00	1.98
10	130.75	32.92	5.74	-.38	.38
11	.06	.00	---	-.00	---
12	.25	.00	---	-.52	-.51
13	15.58	3.18	1.78	-.13	-.13

WEST OF MACKENZIE DELTA BOTTOM (15-20 cm)

Variable	Mean	s^2	S.D.	Skewness	z
2	43.23	75.58	8.69	1.23	1.56
3	52.43	74.63	8.64	-.20	-.25
4	1.02	.00	---	-1.36	-1.72
5	714.14	1925.81	43.88	-2.27	-2.87
6	83.14	20.81	4.56	.49	.62
7	29.00	3.33	1.82	-.92	-1.16
8	3.4	.06	.24	.07	.09
9	38.00	5.33	2.3	.57	.72
10	116.71	50.9	7.13	.29	.37
11	.06	.00	---	-.70	-.89
12	.20	.00	---	-.65	-.82
13	16.16	1.34	1.16	.15	.19

WEST OF MACKENZIE DELTA SURFACE (0-5 cm)

Variable	Mean	s^2	S.D.	Skewness	z
2	40.36	128.86	11.35	.83	1.11
3	55.21	184.46	13.58	-.30	-.40
4	1.07	.02	.14	1.62	2.16
5	733.0	9050.00	95.13	1.87	2.49
6	84.38	136.84	11.70	.54	.72
7	30.5	12.29	3.51	.11	.15
8	3.74	.11	.33	-.36	.48
9	39.88	28.98	5.38	.00	---
10	120.63	330.27	18.17	.03	.04
11	.07	.00	---	.13	.17
12	17.04	2.73	1.65	-.03	-.04
13	16.16	1.34	1.16	.15	.19

APPENDIX D

RESULTS OF TEST FOR HOMOSCEDASTICITY (FIRST TEST)

largest n = 15 = 3.75 ------- Should be <4.0
smallest n 4

All stations:

			Variable
Largest s^2 =	146.28	= 6.23	2
Smallest s^2	23.48		
	184.46	= 5.95	3
	31.00		
	.03	= 1.50	4
	.02		
	9050.00	= 11.02	5
	820.92		
	136.84	= 6.58	6
	20.81		
	28.98	= 8.70	7
	3.33		
	.11	= 3.67	8
	.03		
	28.98	= 5.44	9
	5.33		
	330.27	= 10.03	10
	32.92		
	? all 0.0's		11
	? 3.00's + 0.2		12
	3.18	= 2.37	13
	1.34		

APPENDIX E

RESULTS OF TEST FOR HOMOSCEDASTICITY (SECOND TEST)

REGRESSIONS S.D. vs x

VARIABLE	E-S		E-B		W-S		W-B		SLOPE	H_0:SLOPE=0
2	4.85	47.13	12.09	46.35	11.35	40.36	8.69	43.23	-.495	p=.53
3	5.57	51.91	13.18	52.8	13.58	55.21	8.64	52.43	1.997	p=.24
4	.17	1.17	.17	1.14	.14	1.07	--	1.02	0.323	p=.19
5	33.06	846.13	28.65	859.25	95.13	733.0	43.88	714.14	-0.268	p=.34
6	5.53	79.2	7.41	79.75	11.7	84.38	4.56	83.14	0.625	p=.50
7	3.09	29.67	2.52	28.5	3.51	30.5	1.82	29.00	0.67	p=.21
8	.17	3.5	.20	3.56	.33	3.74	.24	3.4	0.33	p=.32
9	2.79	41.33	3.5	42.75	5.38	39.88	2.3	38.0	0.10	p=.85
10	10.64	135.33	5.74	130.75	18.17	120.63	7.13	116.71	-0.14	p=.78
11	---	.07	---	.06	---	.07	---	.06	---	----
12	.14	.33	---	.25	---	.20	---	.20	---	----
13	1.63	16.99	1.78	15.58	1.65	17.04	1.16	16.16	0.01	p=.97

APPENDIX F

COMPLETE DATA SET FOR ALKANES

ALKANES IN BEAUFORT SEA SEDIMENTS (NANOGRAMS/GRAM, AIR DRY BASIS)

SAMPLE ID	C12	C13	C14	C15	C16	C17	C18	C19	C20
1 0-5 cm	148	106	361	195	282	179	171	163	113
2 0-5 cm	57	59	162	116	192	117	101	104	66
Shbs.Stn.2-7	121	83	278	180	270	194	182	160	100
3-1 0-5 cm	97	85	259	175	276	183	182	152	109
3-2 Top 5 cm	83	73	223	173	200	128	122	115	77
3-2 Top 5 cm	35	38	229	176	266	153	132	137	89
4-1 0-5 cm	39	40	131	78	98	67	48	52	30
4-1 16-bott.	54	50	172	114	161	140	117	120	77
4-2 0-5 cm	60	52	112	74	101	66	60	68	54
4-3 0-5 cm	59	54	151	104	131	95	79	70	89
4-3 0-5 cm	54	49	145	88	120	85	76	81	68
5-1 0-5 cm	5	60	180	130	194	140	131	139	91
5-1 15-20 cm	41	42	167	92	112	71	66	72	50
5-2 0-5 cm	30	34	130	98	158	105	111	127	73
5-2 15-20 cm	60	45	160	95	173	102	95	100	76
6-1 0-5 cm	60	47	145	99	136	121	88	97	76
7-1 0-5 cm	129	92	283	191	275	194	179	151	105
7-1 15-Bot	90	76	241	152	240	141	139	153	96
7-2 0-5 cm	48	48	155	100	100	113	116	131	83
7-2 15-20 cm	219	126	314	186	224	148	136	128	90
7-2 15-20 cm	216	152	239	191	234	140	128	111	87
8-1 0-5 cm	74	61	204	157	174	120	91	94	55
8-2 0-5 cm	87	76	228	128	165	114	94	89	63
8-2 15-Bottom	42	40	97	68	81	63	52	61	48
8-2 15-Bottom	36	37	98	75	86	65	51	47	35
9-1 0-5 cm	87	61	163	99	122	83	75	90	63
9-2 0-Bottom	44	42	129	90	116	82	64	57	42
9-2 0-Bottom	39	38	112	79	106	75	61	59	41
11-1 0-5 cm	68	53	169	115	158	127	107	109	74
11-2 0-5 cm	51	54	169	106	157	120	104	92	76
12-1 0-5 cm	121	113	412	233	349	223	208	221	144
12-2 0-5 cm	59	47	162	121	202	147	126	150	87
McKBv Stn.12	94	57	248	83	183	108	102	85	81
13-1 0-5 cm	201	155	488	300	402	266	260	239	193
13-2 0-5 cm	173	139	429	262	418	248	251	255	192
14-1 0-Bottom	01	53	211	79	169	79	65	48	39
14-1 0-Bottom	80	45	156	61	173	82	77	37	37
14-2 0-Bottom	39	18	98	51	96	66	62	57	40
14-2 0-Bottom	20	21	143	57	124	56	72	62	41
21-1 0-5 cm	94	32	222	60	147	64	80	84	58

SAMPLE ID	C12	C13	C14	C15	C16	C17	C18	C19	C20
21-2 0-5 cm	51	18	144	41	101	44	51	61	40
22-1 0-5 cm	88	50	258	117	172	113	117	102	122
22-1 15-20 cm	105	43	278	121	216	121	126	102	103
22-2 0-5 cm	134	56	372	117	238	125	145	140	145
22-2 15-20 cm	87	49	243	127	231	127	123	81	90
22-2 15-20 cm	86	45	245	120	231	127	133	74	94
23-1 0-5 cm	113	59	299	153	262	164	133	141	77
23-1 15-20 cm	68	43	206	103	193	113	112	79	87
23-2 0-5 cm	117	54	241	94	164	92	101	111	105
23-2 15-20 cm	56	42	147	65	120	78	82	87	78
23-2 15-20 cm	43	29	147	82	148	89	86	65	54

ALKANES IN BEAUFORT SEA SEDIMENTS (NANOGRAMS/GRAM, AIR DRY BASIS)

SAMPLE ID	C21	C22	C23	C24	C25	C26	C27	C28	C29
1 0-5 cm	109	59	83	32	52	8	67	4	14
2 0-5 cm	58	34	40	19	39	7	60	ND	7
Shbs.Stn. 2-7	83	42	55	24	43	ND	31	ND	12
3-1 0-5 cm	96	48	67	24	41	ND	54	ND	11
3-2 Top 5 cm	70	37	51	23	41	ND	42	ND	12
3-2 Top 5 cm	84	51	64	25	53	ND	58	ND	13
4-1 0-5 cm	26	17	23	12	59	ND	31	8	16
4-1 16-Bottom	76	44	56	28	46	13	43	ND	8
4-2 0-5 cm	71	47	93	39	97	38	100	12	28
4-3 0-5 cm	69	48	72	27	82	28	109	29	19
4-3 0-5 cm	81	52	89	31	94	26	109	34	26
5-1 0-5 cm	57	41	47	26	55	7	50	18	14
5-1 15-20 cm	55	34	52	20	54	12	66	9	15
5-2 0-5 cm	65	35	44	21	34	ND	45	ND	11
5-2 15-20 cm	60	41	50	21	38	ND	37	ND	8
6-1 0-5 cm	69	42	46	23	46	ND	45	ND	9
7-1 0-5 cm	98	43	49	24	47	ND	52	ND	13
7-1 15-Bottom	86	45	51	25	46	ND	50	ND	8
7-2 0-5 cm	73	30	39	22	53	ND	49	ND	8
7-2 15-20 cm	87	57	80	33	68	16	65	9	18
7-2 15-20 cm	80	56	73	28	72	12	69	8	16
8-1 0-5 cm	50	32	43	23	54	21	97	23	27
8-2 0-5 cm	58	35	27	23	50	5	69	6	14
8-2 15-Bottom	51	34	60	29	75	25	109	11	22
8-2 15-Bottom	50	30	59	30	72	26	113	11	14
9-1 0-5 cm	69	50	71	36	90	20	117	18	27
9-2 0-Bottom	34	20	31	18	40	13	61	9	15
9-2 0-Bottom	36	25	35	18	36	8	59	13	20
11-1 0-5 cm	70	41	54	31	65	12	76	ND	12
11-2 0-5 cm	61	39	53	25	44	7	39	ND	11
12-1 0-5 cm	140	85	112	57	114	18	121	ND	28
12-2 0-5 cm	78	51	33	25	62	9	52	2	11
McKBv Stn.12-BB	120	56	161	38	140	22	210	16	200
13-1 0-5 cm	211	102	157	63	167	27	236	ND	86
13-2 0-5 cm	220	127	174	78	139	14	113	ND	30
14-1 0-Bottom	44	30	26	16	31	ND	46	22	46
14-1 0-Bottom	27	21	27	15	33	6	41	17	50
14-2 0-Bottom	29	21	29	13	33	8	58	11	19
14-2 0-Bottom	44	29	52	19	56	10	82	7	30
21-1 0-5 cm	78	46	96	35	147	26	185	8	55

SAMPLE ID	C21	C22	C23	C24	C25	C26	C27	C28	C29
21-2 0-5 cm	44	32	71	32	96	26	130	15	48
22-1 0-5 cm	134	85	200	71	299	52	346	ND	282
22-1 15-20 cm	119	77	161	67	192	28	362	ND	155
22-2 0-5 cm	183	106	226	55	151	21	181	4	70
22-2 15-20 cm	47	38	70	35	86	22	183	18	91
22-2 15-20 cm	43	41	70	40	92	12	184	10	91
23-1 0-5 cm	81	49	113	44	151	28	222	29	128
23-1 15-20 cm	104	65	125	45	149	34	283	25	119
23-2 0-5 cm	139	78	176	57	194	40	336	31	142
23-2 15-20 cm	103	61	137	46	226	29	217	26	72
23-2 15-20 cm	98	51	140	44	264	31	202	24	65

SAMPLE ID	C30	C31	C32	C33	C34	C35	C36	TOTAL N-ALKANE	PRIS.	PHYTANE
1 0-5 cm	ND	52	ND	26	ND	ND	ND	2304	193	134
2 0-5 cm	ND	42	14	17	ND	ND	ND	1310	126	74
Shos.St 2-7	ND	55	ND	32	ND	ND	ND	1946	223	154
3-1 0-5 cm	ND	42	16	15	ND	ND	ND	1931	214	7e
3-2 Too 5 cm	ND	33	16	8	ND	ND	ND	1527	137	82
3-2 Too 5 cm	ND	47	25	12	ND	ND	ND	1687	169	93
4-1 0-5 cm	6	51	30	35	8	5	ND	912	71	39
4-1 16-Bottom	ND	33	16	13	ND	ND	ND	1378	151	108
4-2 0-5 cm	14	68	73	26	ND	ND	ND	1353	55	45
4-3 0-5 cm	ND	65	34	25	ND	ND	ND	1439	92	57
4-3 0-5 cm	ND	72	41	26	ND	ND	ND	1448	99	66
5-1 0-5 cm	ND	36	16	14	ND	ND	ND	1452	170	116
5-1 15-20 cm	6	49	34	18	13	12	ND	1162	79	48
5-2 0-5 cm	ND	44	16	4	ND	ND	ND	1184	123	82
5-2 15-20 cm	ND	26	11	7	ND	ND	ND	1206	117	70
6-1 0-5 cm	ND	37	18	14	ND	ND	ND	1217	124	69
7-1 0-5 cm	ND	40	ND	ND	ND	ND	ND	1965	213	140
7-1 15-Bottom	ND	32	12	ND	ND	ND	ND	1683	155	105
7-2 0-5 cm	ND	19	ND	ND	ND	ND	ND	1270	130	88
7-2 15-20 cm	ND	47	23	ND	ND	ND	ND	2073	152	99
7-2 15-20 cm	6	51	14	ND	ND	ND	ND	1981	86	ND
8-1 0-5 cm	ND	90	90	30	ND	ND	ND	1610	127	68
8-2 0-5 cm	ND	36	22	20	ND	ND	ND	1408	114	72
8-2 15-Bottom	13	53	34	25	10	13	ND	1116	74	45
8-2 15-Bottom	16	46	26	22	11	12	ND	1069	70	47
9-1 0-5 cm	27	83	32	41	22	21	ND	1567	94	65
9-2 0-Bottom	10	45	19	ND	ND	ND	ND	984	71	51
9-2 0-Bottom	12	44	31	ND	ND	ND	ND	949	76	47
11-1 0-5 cm	ND	29	ND	ND	4	ND	ND	1373	142	97
11-2 0-5 cm	ND	45	18	9	ND	ND	ND	1283	138	83
12-1 0-5 cm	ND	110	262	33	ND	ND	ND	3103	243	164
12-2 0-5 cm	ND	34	19	12	ND	ND	ND	1488	152	95
McKBv St.12-8	ND	256	64	54	ND	ND	ND	2376	164	78
13-1 0-5 cm	ND	253	ND	67	ND	ND	ND	3874	318	205
13-2 0-5 cm	ND	106	40	23	ND	ND	ND	3431	274	203
14-1 0-Bottom	6	108	20	35	ND	ND	ND	1255	58	31
14-1 0-Bottom	6	114	14	32	ND	ND	ND	1152	53	32
14-2 0-Bottom	ND	82	16	34	ND	ND	ND	880	50	44
14-2 0-Bottom	7	113	19	37	ND	ND	ND	1101	57	38
21-1 0-5 cm	14	145	40	46	ND	ND	ND	1761	66	31

SAMPLE ID	C30	C31	C32	C33	C34	C35	C36	TOTAL N-ALKANE	PRIS.	PHYTANE
21-2 0-5 cm	12	153	26	53	ND	ND	ND	1288	40	26
22-1 0-5 cm	ND	356	111	173	ND	ND	ND	3348	123	66
22-1 15-20 cm	ND	95	ND	19	ND	ND	ND	2492	109	70
22-2 0-5 cm	ND	186	22	33	ND	ND	ND	2709	140	78
22-2 15-20 cm	12	307	82	72	ND	ND	ND	2219	98	59
22-2 15-20 cm	4	318	90	61	ND	ND	ND	2212	111	56
23-1 0-5 cm	21	429	159	115	ND	ND	ND	2971	147	70
23-1 15-20 cm	27	339	77	80	ND	ND	ND	2475	111	69
23-2 0-5 cm	22	411	75	95	ND	ND	ND	2875	85	61
23-2 15-20 cm	8	207	82	69	ND	ND	ND	2077	74	53
23-2 15-20 cm	6	195	62	59	ND	ND	ND	1981	77	45

SAMPLE ID	C12	C13	C14	C15	C16	C17	C18	C19	C20
24-2 0-5 cm	116	38	217	69	142	80	88	91	75
24-2 15-Bot.	103	62	275	103	152	94	86	126	80
25-1 0-5 cm	121	63	330	111	247	124	144	134	96
25-1 15-20 cm	49	33	144	70	105	59	61	83	64
25-2 0-5cm	138	68	360	127	266	125	140	145	104
25-2 15-20cm	119	65	336	132	248	129	129	113	93
26-1 0-5cm	150	73	398	128	265	118	145	142	114
26-1 15-20cm	104	53	314	101	226	104	115	102	103
26-2 0-5cm	152	72	405	134	315	113	143	126	103
26-2 15-20cm	63	31	190	67	167	79	87	66	60
#27 Grab	30	12	73	16	61	20	28	17	23
#27 Grab	29	14	65	26	62	29	26	21	18
#28 Grab	72	6	110	11	67	20	31	14	20
#28 Grab	67	7	104	12	77	21	30	15	21
29-1 0-5	50	44	111	68	92	62	37	43	37
29-2 0-5	103	97	296	202	269	189	155	183	129
Surf St. 10	44	62	158	117	152	115	92	143	88
Surf St. 10	46	64	183	131	155	119	98	143	85
30 Grab Only	28	3	64	4	48	8	17	3	7
30 Grab Only	26	3	60	4	41	7	17	3	7
31-1 0-5	54	53	156	130	164	119	89	82	64
31-1 15-20	54	56	142	109	153	113	99	99	76
31-2 0-5	167	133	345	238	278	206	174	175	120
31-2 15-20	76	79	213	174	221	138	118	104	73
32-1 0-5	71	53	155	103	149	101	100	125	88
32-2 0-5	90	83	247	174	235	181	170	171	114
33-1 0-5	246	175	500	274	306	199	159	126	103
33-2 0-5	123	127	255	181	221	232	171	172	118
34-1 0-5	130	82	285	145	215	128	129	135	97
34-1 15-20	53	33	220	86	159	90	97	63	64
34-2 0-5cm	89	74	229	139	194	136	130	146	102
34-2 15-20	60	46	156	92	133	113	90	134	97
#36 Grab Only	32	14	107	46	121	56	62	25	27
#36 Grab Only	28	14	99	48	110	54	55	24	24
#37 Grab Only	31	11	127	17	82	19	26	11	19
#37 Grab Only	29	11	125	17	81	19	27	11	18
MB 4-1 0-4	172	55	548	107	367	76	124	82	65
BSO 15-1 0-5cm	192	81	638	147	493	149	195	142	110
BSO 15-2 0-5cm	225	96	697	180	522	161	212	154	119
BSO 16-1 0-5cm	335	41	746	57	350	54	104	49	47

SAMPLE ID	C21	C22	C23	C24	C25	C26	C27	C28	C29
24-2 0-5 cm	90	56	135	43	178	31	289	20	111
24-2 15-Bot.	110	72	168	60	203	40	280	20	124
25-1 0-5 cm	119	62	121	38	115	13	251	ND	103
25-1 15-20 cm	72	73	140	60	228	71	358	92	164
25-2 0-5 cm	124	78	156	60	170	45	343	ND	107
25-2 15-20 cm	122	73	153	55	145	28	199	6	88
26-1 0-5 cm	142	90	107	68	257	40	405	31	151
26-1 15-20 cm	130	81	196	60	255	36	381	14	167
26-2 0-5 cm	169	87	244	81	333	49	724	80	346
26-2 15-20 cm	78	49	118	45	156	63	258	57	108
#27 GRAB	9	10	8	5	15	ND	21	ND	ND
#27 GRAB	8	9	8	5	17	5	26	ND	ND
#28 GRAB	7	9	9	6	15	ND	18	ND	7
#28 GRAB	7	10	9	7	16	ND	19	ND	6
29-1 0-5 cm	38	26	37	21	41	11	52	31	10
29-2 0-5 cm	129	77	110	50	129	31	140	24	31
Surf Sta 10	102	61	83	33	71	26	85	14	27
Surf Sta 10	95	56	82	31	74	17	84	7	25
#30 GRAB ONLY	4	6	ND	4	5	ND	ND	ND	ND
#30 GRAB ONLY	4	6	ND	4	5	ND	ND	ND	ND
31-1 0-5 cm	53	33	36	25	43	8	43	6	19
31-1 15- 20 cm	65	43	53	23	42	ND	39	ND	10
31-2 0-5 cm	124	78	129	49	172	70	197	66	64
31-2 15-20 cm	74	50	64	31	60	13	74	14	22
32-1 0-5 cm	79	51	66	37	85	16	97	12	23
32-2 0-5 cm	105	57	71	27	52	12	62	ND	7
33-1 0-5 cm	99	62	98	52	121	35	199	21	50
33-2 0-5 cm	129	71	101	56	114	34	161	38	70
34-1 0-5 cm	106	64	92	39	124	32	132	21	34
34-1 15-20 cm	62	42	58	31	57	5	56	ND	11
34-2 0-5 cm	108	63	97	46	102	29	161	25	51
34-2 15-20 cm	77	49	61	25	54	7	51	ND	15
#36 GRAB ONLY	9	11	7	6	12	ND	11	ND	ND
#36 GRAB ONLY	9	9	8	5	11	4	14	ND	5
#37 GRAB ONLY	10	10	7	ND	6	ND	5	ND	6
#37 GRAB ONLY	10	10	7	ND	6	ND	10	ND	6
#37 GRAB ONLY	66	45	70	33	58	16	57	ND	ND
BSD 15-1 0-5 cm	144	76	159	56	175	86	248	16	77
BSD 15-2 0-5 cm	154	82	160	57	170	27	216	ND	68
BSD 16-1 0-5 cm	52	36	61	ND	78	ND	86	ND	20

SAMPLE ID	C30	C31	C32	C33	C34	C35	C36	TOTAL	PRIS.	PHYTANE	PRIS./PHYTANE N-ALKANE
24-2 0-5 cm	12	324	58	76	9	ND	ND	2348	73	53	1.38
24-2 15-Bot.	24	323	130	105	ND	ND	ND	2743	85	56	1.52
25-1 0-5 cm	ND	311	60	82	ND	ND	ND	2644	113	182	0.62
25-1 15-20 cm	95	482	147	108	ND	ND	ND	2758	55	42	1.31
25-2 0-5 cm	ND	392	94	131	ND	ND	ND	3174	113	75	1.51
25-2 15-20 cm	ND	284	ND	130	ND	ND	ND	2649	115	82	1.40
26-1 0-5 cm	33	483	176	184	ND	ND	ND	3779	105	81	1.30
26-1 15-20 cm	ND	494	276	193	ND	ND	ND	3506	98	69	1.42
26-2 0-5 cm	38	1247	371	313	ND	ND	ND	5643	106	68	1.56
26-2 15-20 cm	19	333	115	70	ND	ND	ND	2279	65	41	1.59
#27 GRAB	ND	18	ND	ND	ND	ND	ND	368	15	12	1.25
#27 GRAB	ND	13	ND	ND	ND	ND	ND	382	14	10	1.40
#28 GRAB	5	48	24	46	43	33	17	637	12	11	1.09
#28 GRAB	5	37	17	36	41	30	18	607	13	9	1.44
29-1 0-5 cm	ND	29	19	9	ND	ND	ND	869	68	38	1.79
29-2 0-5 cm	ND	99	64	ND	ND	ND	ND	2508	219	129	1.70
Surf Sta 10	16	70	37	38	ND	ND	ND	1634	116	95	1.22
Surf Sta 10	8	65	29	39	ND	ND	ND	1636	129	82	1.57
30 GRAB ONLY	ND	ND	ND	ND	ND	ND	ND	201	4	2	2.00
30 GRAB ONLY	ND	ND	ND	ND	ND	ND	ND	190	4	2	2.00
31-1 0-5 cm	ND	48	39	29	12	ND	ND	1300	123	67	1.84
31-1 15-20 cm	ND	38	13	10	ND	ND	ND	1238	118	75	1.57
31-2 0-5 cm	ND	169	ND	ND	ND	ND	ND	2953	215	138	1.56
31-2 15-20 cm	ND	72	41	35	ND	ND	ND	1744	146	87	1.68
32-1 0-5 cm	6	67	40	26	ND	ND	ND	1552	120	84	1.43
32-2 0-5 cm	ND	55	ND	ND	ND	ND	ND	1913	207	139	1.49
33-1 0-5 cm	23	95	60	32	ND	ND	ND	3036	196	131	1.50
33-2 0-5 cm	ND	135	76	ND	ND	ND	ND	2586	199	169	1.18
34-1 0-5 cm	ND	99	ND	ND	ND	ND	ND	2085	144	97	1.48
34-1 15-20 cm	ND	42	ND	ND	ND	ND	ND	1230	95	60	1.58
34-2 0-5 cm	ND	195	ND	ND	ND	ND	ND	2117	158	94	1.68
34-2 15-20 cm	ND	53	18	16	ND	ND	ND	1346	117	66	1.77
#36 GRAB ONLY	ND	ND	ND	ND	ND	ND	ND	547	37	26	1.42
#36 GRAB ONLY	ND	ND	ND	ND	ND	ND	ND	522	34	23	1.48
#37 GRAB ONLY	ND	22	5	ND	ND	ND	ND	415	18	9	2.00
#37 GRAB ONLY	ND	21	5	4	ND	ND	ND	417	18	9	2.00
MB 4-1 0-4	ND	ND	ND	ND	ND	ND	ND	1941	77	53	1.45
BSD 15-1 0-5 cm	23	241	98	82	ND	ND	ND	3628	164	110	1.49
BSD 15-2 0-5 cm	10	193	82	55	ND	ND	ND	3640	159	89	1.79
BSD 16-1 0-5 cm	ND	84	ND	ND	ND	ND	ND	2205	41	31	1.32

SAMPLE ID	C12	C13	C14	C15	C16	C17	C18	C19	C20
BSO 16-1 0-5cm	372	46	839	64	391	60	112	52	51
BSO 16-1 15-20cm	391	108	806	128	398	101	146	110	79
BSO 16-2 0-5cm	169	65	610	86	408	72	161	82	88
BSO 17-2 0-5cm	205	48	504	76	365	77	150	68	75
BSO 17-2 0-5cm	201	44	508	74	364	78	148	66	72
BSO 18-1 0-5cm	229	86	641	167	475	165	229	189	131
BSO 18-2 0-5cm	231	82	635	141	459	144	199	135	114
BSO 18-3 0-5cm	173	92	636	162	491	152	205	202	123
BSO 19-1 0-5cm	175	77	581	157	465	150	208	145	135
BSO 19-1 15-20cm	136	38	389	88	297	95	102	67	68

SAMPLE ID	C21	C22	C23	C24	C25	C26	C27	C28	C29
BSO 16-1 0-5 cm	55	40	67	ND	87	ND	94	ND	29
BSO 16-1 15-20 cm	120	69	177	68	194	26	205	ND	69
BSO 16-2 o-5 cm	133	78	226	59	208	20	285	ND	81
BSO 17-2 0-5 cm	108	72	179	68	202	35	233	ND	76
BSO 17-2 0-5 cm	107	69	172	63	198	29	211	ND	68
BSO 18-1 0-5 cm	199	119	253	91	299	56	349	33	112
BSO 18-2 0-5 cm	169	87	185	57	193	35	272	36	77
BSO 18-3 0-5 cm	132	98	197	101	370	27	250	17	82
BSO 19-1 0-5 cm	166	88	174	48	150	22	197	11	72
BSO 19-1 15-20 cm	86	58	121	60	247	47	434	35	216

SAMPLE ID	C30	C31	C32	C33	C34	C35	C36	TOTAL N-ALKANE	PRIS.	PHYTANE
BSO 16-1 0-5 cm	ND	93	ND	ND	ND	ND	ND	2453	45	34
BSO 16-1 15-20 cm	ND	189	ND	ND	ND	ND	ND	3382	90	63
BSO 16-2 0-5 cm	ND	211	70	68	ND	ND	ND	3177	47	37
BSO 17-2 0-5 cm	ND	216	ND	ND	ND	ND	ND	2758	63	49
BSO 17-2 0-5 cm	ND	184	ND	ND	ND	ND	ND	2656	62	51
BSO 18-1 0-5 cm	23	320	111	109	ND	ND	ND	4386	164	114
BSO 18-2 0-5 cm	11	219	79	82	ND	ND	ND	3643	147	88
BSO 18-3 0-5 cm	36	256	86	60	ND	ND	ND	3954	168	97
BSO 19-1 0-5 cm	ND	178	53	64	ND	ND	ND	3309	162	99
BSO 19-1 15-20 cm	51	778	148	76	ND	ND	ND	3629	83	48

SAMPLE ID	C12	C13	C14	C15	C16	C17	C18	C19	C20
BSO 19-2 0-5 cm	127	65	458	125	397	138	193	140	114
BSO 19-2 15-20 cm	134	76	546	168	442	136	203	131	109
BSO 19-3 0-5 cm	171	57	507	128	407	148	202	163	113
BSA 19-3 15-20 cm	178	62	546	138	442	146	190	165	139
BSO 20-1 0-5 cm	380	60	616	86	335	84	124	78	68
BSO 20-1 15-20 cm	337	102	661	159	412	151	183	126	115
BSO 20-2 0-5 cm	507	77	763	105	426	91	150	91	77
BSO 20-2 0-5 cm	480	73	727	99	417	89	146	91	74
BSO 20-2 15-20 cm	297	98	534	156	379	141	150	104	99
BSO #38 GRAB ONLY	112	46	320	101	315	119	151	108	86
BSO #38 GRAB ONLY	115	45	333	101	317	117	149	108	85
BSO #39 GRAB ONLY	123	66	359	130	268	123	115	85	68
BSO 40-1 0-5 cm	264	93	727	197	522	186	255	166	141
BSO 40-2 0-5 cm	256	88	659	174	476	173	212	150	122
BSO #41 GRAB ONLY	122	9	273	11	104	12	29	8	12
BSO #41 GRAB ONLY	118	9	282	11	105	13	29	8	12
BSO 42-1 0-5 cm	200	50	597	91	378	76	147	70	78
BSO 42-2 0-5 cm	168	59	565	85	332	52	111	61	72
BSO #43 GRAB ONLY	105	6	251	7	101	11	25	5	8
BSO #43 GRAB ONLY	106	6	256	7	95	10	24	4	8

SAMPLE ID	C21	C22	C23	C24	C25	C26	C27	C28	C29
BSD 19-2 0-5 cm	150	91	192	74	201	37	294	43	75
BSD 19-2 15-20 cm	147	89	160	62	192	32	249	ND	28
BSD 19-3 0-5 cm	163	85	182	59	174	35	253	ND	72
BSA 19-3 15-20 cm	199	105	196	71	198	41	246	ND	119
BSD 20-1 0-5 cm	72	50	93	39	118	29	165	ND	61
BSD 20-1 15-20 cm	128	174	148	54	119	32	162	ND	62
BSD 20-2 0-5 cm	85	61	104	47	139	21	198	13	63
BSD 20-2 0-5 cm	86	57	105	47	144	26	197	17	60
BSD 20-2 15-20 cm	114	72	124	57	136	23	150	ND	54
BSD #38 GRAB ONLY	71	43	59	30	62	15	79	ND	9
BSD #38 GRAB ONLY	70	43	59	25	61	14	64	ND	8
BSD #39 GRAB ONLY	63	38	56	32	70	21	91	ND	17
BSD 40-1 0-5 cm	135	80	137	52	134	16	146	20	26
BSD 40-2 0-5 cm	105	65	115	37	95	19	112	5	30
BSD #41 GRAB ONLY	11	11	14	9	34	ND	42	ND	8
BSD #41 GRAB ONLY	11	9	11	7	30	ND	48	ND	12
BSD 42-1 0-5 cm	79	50	92	36	93	21	91	ND	29
BSD 42-2 0-5 cm	72	49	101	42	102	20	114	ND	27
BSD #43 GRAB ONLY	6	7	10	5	17	ND	24	ND	8
BSD #43 GRAB ONLY	6	6	8	4	14	ND	30	ND	4

SAMPLE ID	C30	C31	C32	C33	C34	C35	C36	TOTAL N-ALKANE	PRIS.	PHYTANE
BSO 19-2 0-5 cm	ND	209	ND	ND	ND	ND	ND	3124	118	86
BSO 19-2 15-20 cm	ND	228	ND	ND	ND	ND	ND	3130	113	77
BSO 19-3 0-5 cm	ND	166	ND	ND	ND	ND	ND	3084	164	102
BSA 19-3 15-20 cm	ND	321	ND	ND	ND	ND	ND	3501	147	99
BSO 20-1 0-5 cm	ND	145	ND	ND	ND	ND	ND	2671	74	54
BSO 20-1 15-20 cm	ND	146	ND	ND	ND	ND	ND	3169	123	88
BSO 20-2 0-5 cm	ND	191	ND	ND	ND	ND	ND	3211	75	56
BSO 20-2 0-5 cm	ND	187	ND	ND	ND	ND	ND	3121	71	54
BSO 20-2 15-20 cm	ND	142	ND	ND	ND	ND	ND	2830	118	79
BSO #38 GRAB ONLY	ND	ND	ND	ND	ND	ND	ND	1727	118	80
BSO #38 GRAB ONLY	ND	ND	ND	ND	ND	ND	ND	1716	118	84
BSO #39 GRAB ONLY	ND	50	ND	ND	ND	ND	ND	1774	146	79
BSO 40-1 0-5 cm	ND	84	ND	ND	ND	ND	ND	3379	234	135
BSO 40-2 0-5 cm	14	93	ND	ND	ND	ND	ND	2998	215	118
BSO #41 GRAB ONLY	ND	32	ND	ND	ND	ND	ND	739	16	9
BSO #41 GRAB ONLY	ND	35	ND	ND	ND	ND	ND	750	15	8
BSO 42-1 0-5 cm	ND	86	ND	ND	ND	ND	ND	2263	85	55
BSO 42-2 0-5 cm	ND	ND	ND	ND	ND	ND	ND	2031	87	53
BSO #43 GRAB ONLY	ND	28	ND	ND	ND	ND	ND	624	29	5
BSO #43 GRAB ONLY	ND	14	ND	ND	ND	ND	ND	601	4	ND

APPENDIX G

COMPLETE DATA SET FOR PARTICLE SIZE, TOTAL ORGANIC CARBON, AND METALS

Particle size, total organic carbon, and metal concentrations in Beaufort Sea sediments (metal values in $ug.g^{-1}$)

Station		Particle Size			Total organic carbon (%)	Metals								
		Sand (%)	Silt (%)	Clay (%)		Barium	Chromium	Copper	Iron (%)	Nickel	Zinc	Mercury $ng.g^{-1}$	Cadmium $ng.g^{-1}$	Lead
1	0 - 5 cm	0.80	52.90	46.30	0.87	804	75	24	3.16	35	137	60	430	17.9
2	0 - 5 cm	0.30	48.70	51.00	1.03	841	77	28	3.51	41	136	70	750	16.3
3	0 - 5 cm	0.20	46.40	53.50	1.26	808	79	29	3.45	39	131	60	380	16.9
4	0 - 5 cm	0.50	44.40	55.10	1.14	855	80	29	3.65	40	137	60	270	19.0
5	0 - 5 cm	0.50	47.20	52.50	1.28	835	84	30	3.49	43	141	70	200	18.5
5	15 -20 cm	0.40	43.90	55.80	1.16	842	85	29	3.55	41	136	70	210	17.1
6	0 - 5 cm	0.80	40.20	59.20	1.09	892	84	32	3.73	43	151	70	240	18.6
7	0 - 5 cm	0.60	47.20	52.00	1.32	920	82	32	3.65	42	137	80	240	18.6
7	15 -20 cm	2.90	61.30	36.00	0.95	844	70	25	3.34	41	124	60	280	13.7
8	0 - 5 cm	0.10	39.60	60.30	1.66	848	84	37	3.78	45	157	90	360	19.9
8	15 -20 cm	0.30	48.20	51.50	1.37	849	78	29	3.51	41	128	70	250	14.4
9	0 - 5 cm	0.60	53.00	46.40	1.27	837	80	29	3.47	46	137	70	333	15.3
11	0 - 5 cm	0.50	50.30	49.30	1.18	803	77	28	3.32	40	129	70	340	15.2
12	0 - 5 cm	0.20	47.80	52.10	1.25	851	90	32	3.61	44	135	80	300	16.7
13	0 - 5 cm	0.80	27.30	72.00	1.35	946	104	35	4.20	43	151	100	300	19.1
14	0 - 5 cm	84.10	5.00	10.90	0.37	457	33	12	2.35	35	62	30	120	7.5
15	0 - 5 cm	19.00	36.00	45.00	1.01	681	76	28	3.98	40	98	70	170	14.8
16	0 - 5 cm	57.60	24.10	18.40	0.57	505	50	17	2.74	38	78	40	90	8.4
16	15 -20 cm	51.20	32.80	16.10	0.76	545	57	20	2.51	37	74	50	120	9.8
17	0 - 5 cm	54.80	23.80	21.40	0.64	631	58	23	3.00	38	86	40	140	10.1
18	0 - 5 cm	1.60	33.10	65.30	1.10	729	94	34	3.98	45	126	80	170	17.6
19	0 - 5 cm	1.70	33.70	64.60	1.07	772	89	34	3.85	48	124	70	180	16.4
19	15 -20 cm	3.10	36.00	60.80	1.07	751	88	30	3.70	42	119	70	140	16.4
20	0 - 5 cm	37.60	35.70	26.80	0.70	589	58	19	2.68	34	81	40	130	10.3
20	15 -20 cm	15.00	36.40	48.70	0.91	734	78	26	3.34	39	111	60	140	14.8

Station	Particle Size			Total organic carbon (%)	Metals								
	Sand (%)	Silt (%)	Clay (%)		Barium	Chromium	Copper	Iron (%)	Nickel	Zinc	Mercury $ng.g^{-1}$	Cadmium $ng.g^{-1}$	Lead
21 0 - 5 cm	83.90	20.70	15.50	0.43	498	49	17	2.31	24	69	30	140	8.8
22 0 - 5 cm	1.60	32.10	63.40	1.13	774	96	34	3.80	40	138	80	310	20.0
22 15 -20 cm	7.30	46.40	46.40	1.05	713	80	29	3.28	38	117	70	240	15.9
23 0 - 5 cm	0.60	33.90	65.60	1.08	726	91	31	3.80	39	131	80	170	19.2
23 15 -20 cm	1.20	37.20	61.70	1.07	730	90	31	3.73	39	129	60	200	18.0
24 0 - 5 cm	8.70	53.40	37.90	1.06	682	74	26	3.47	32	114	50	210	16.7
24 15 -20 cm	2.40	48.20	49.40	0.99	726	84	30	3.29	36	118	70	240	16.5
25 0 - 5 cm	0.80	45.80	53.50	1.00	692	74	29	3.44	38	126	70	180	17.5
25 15 -20 cm	0.70	38.90	60.50	1.01	727	83	30	3.44	37	117	60	200	16.8
26 0 - 5 cm	2.70	59.70	37.70	0.92	636	73	27	3.21	34	95	50	210	15.0
26 15 -20 cm	1.00	59.50	39.50	1.04	618	79	27	3.02	35	106	60	230	14.7
27 0 - 5 cm	98.10	1.60	0.20	0.14	341	10	4	0.80	7	18	10	70	1.4
28 0 - 5 cm	99.40	0.20	0.40	0.08	410	8	4	0.66	7	19	10	30	2.5
29 0 - 5 cm	4.70	46.20	49.20	1.03	831	74	27	3.36	42	114	60	440	16.2
30 0 - 5 cm	99.80	0.10	0.10	0.17	353	11	3	0.78	8	18	0	30	1.7
31 0 - 5 cm	0.20	46.40	53.50	1.08	875	77	31	3.53	41	124	70	270	17.4
31 15 -20 cm	0.20	32.00	67.90	1.06	902	86	31	3.84	48	135	60	250	17.1
32 0 - 5 cm	4.40	57.00	38.60	1.11	821	66	26	3.24	38	123	50	240	13.6
33 0 - 5 cm	0.60	42.50	57.00	0.97	871	79	31	3.57	41	141	60	220	16.8
34 0 - 5 cm	51.70	19.70	28.60	0.67	745	52	20	2.57	29	81	30	180	10.7
34 15 -20 cm	63.50	11.40	25.10	0.58	710	39	16	2.18	23	78	30	140	11.3
36 0 - 5 cm	95.80	1.30	2.90	0.21	648	42	9	2.49	22	45	10	150	6.2
37 0 - 5 cm	97.70	0.90	1.40	0.13	581	25	7	1.39	15	57	10	80	5.7
38 0 - 5 cm	70.80	10.20	19.00	0.48	694	41	11	2.10	31	31	20	100	6.6
39 0 - 5 cm	55.40	18.00	26.00	0.58	699	60	19	2.47	49	49	40	210	10.4
40 0 - 5 cm	21.10	43.20	35.80	0.87	805	59	19	2.86	38	38	40	230	11.8
41 0 - 5 cm	97.70	0.10	2.20	0.15	598	27	7	1.22	18	18	10	40	2.7
42 0 - 5 cm	80.50	6.80	12.80	0.38	671	35	12	2.12	28	28	10	100	5.5
43 0 - 5 cm	97.50	0.80	1.70	0.12	608	37	7	2.17	21	21	10	50	4.3